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THE DEVELOPMENT OF A MODEL FOR PREDICTING PASSENGER ACCEPTANCE OF SHORT-HAUL AIR TRANSPORTATION SYSTEMS

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A. ROBERT K~~U~~HLTHAU AND IRA D. JACOBSON

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DEPARTMENT OF ENGINEERING SCIENCE & SYSTEMS
RESEARCH LABORATORIES FOR THE ENGINEERING SCIENCES
SCHOOL OF ENGINEERING AND APPLIED SCIENCE
UNIVERSITY OF VIRGINIA
CHARLOTTESVILLE, VA

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National Aeronautics and
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Langley Research Center
Hampton, Virginia 23665

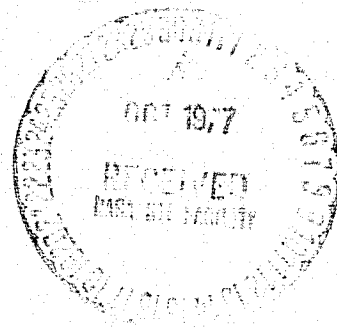


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THE DEVELOPMENT OF A MODEL FOR PREDICTING PASSENGER
ACCEPTANCE OF SHORT-HAUL AIR TRANSPORTATION SYSTEMS

A. Robert Kuhlthau and Ira D. Jacobson

Department of Engineering Science and Systems, University of Virginia

SUMMARY

This report concludes an extensive grant effort which achieved the intended objective of developing meaningful criteria and methodology for assessing the potential acceptability to the traveling public of present and future transportation systems, particularly in the area of ride quality. Major experimental and analytical effort was expended over six years in developing the problem solution plan and test methodologies, in determining the importance of system features to the air traveler, in modeling the travelers' acceptance as a function of ride, in validating models and in applying the models to various situations. Thirty-seven prior publications report these efforts. This final report summarizes the strategies, activities, results, and conclusions, and properly orients the reader to the appropriate publications for details. A complete listing of all publications issued is appended and a brief summary of each is included.

Ride quality was found to be one of the important variables affecting the decision of users of air transportation, and it was found to be influenced by several environmental factors, especially motion, noise, pressure, temperature, and seating. Models were developed to quantify the relationship of subjective comfort to all of these parameters and then they were exercised for a variety of situations. Passenger satisfaction was found to be strongly related to ride quality and was so modeled. A computer program was developed to assess the comfort and satisfaction levels of passengers on aircraft subjected to arbitrary flight profiles over arbitrary terrain. A model was deduced of the manner in which passengers integrate isolated segments of a flight to obtain an overall trip comfort rating. A method was established for assessing the influence of other links (e.g., access, terminal conditions) in the overall passenger trip.

INTRODUCTION

Although there had been about a year of preliminary study and problem formulation under the University of Virginia's Institutional Grant from NASA, the detailed study of the problem began in June 1971, when the current grant was initiated.

The problem had its origins in the results of flight tests conducted by both American Airlines and Eastern Airlines with a prototype of the French military aircraft, the Breguet 941. McDonnell-Douglas was proposing a commercial modification, capitalizing on the amazing short-field landing and take-off characteristics of the aircraft. American and Eastern were independently studying the development of short take-off and landing (STOL) service from possible city center sites in their high density northeastern and midwestern markets (in order to relieve congestion at existing airports and also reduce ground access time), and the 941 seemed like a good prospect.

Accordingly the prototype was tested by both airlines, again independently, and although the aircraft performed beautifully, a large number of regular passengers who were offered rides on the aircraft objected, many of them strenuously, to the quality of the ride. The principal complaint was to the motion of the vehicle in flight.

Although the technology for stability augmentation to provide ride smoothing is available, it is expensive, not only through direct cost, but also because it imposes a variety of penalties on the aerodynamic performance of the vehicle. Thus it became important to determine not only the extent to which ride smoothing was required, but also the particular components of the motion to which the passengers were most sensitive. In short, before design modifications were feasible, it was necessary to develop proper ride quality criteria against which potential designs could be evaluated.

It was to this question of the development of ride quality criteria that the present work has been directed. The problem statement as given in the original proposal is as follows:

"To develop criteria based on quantitative reasoning for the assessment of the potential acceptability to the appropriate traveling public of present and future STOL transportation systems; and to develop a method for application of the criteria to the systems and their component parts not only to predict acceptance but also to indicate areas where improvement would be most desirable and effective."

Although a few minor modifications have taken place (e.g., recognizing that similar ride quality problems are inherent in the type of aircraft used by third-level or "commuter" carriers, STOL has been changed to short haul) during the course of the project, the objectives have remained essentially the same.

To achieve these objectives has required a major effort. For example, during the past six years over 40 technical reports and publications have resulted from the work. These cover a large range of activities, and to review them all in detail at this time would give rise to a document of such size as to be discouraging to the prospective reader. Thus the intent of this final report is to summarize the strategies, activities, results, and conclusions of the work and to properly orient the reader to the bibliography should more detail be desired on various facets. A complete listing of all publications issued under the grant is appended, and a brief summary of the nature of each is included.

PROBLEM SOLUTION PLAN

In order to properly address the problem of the development of ride quality acceptance criteria, it is essential that it be placed in its proper perspective with regard to all the issues involved in the acceptance of a transportation system.

The general approach adopted for the study was to assume that the system which constituted acceptance of any transportation service was as shown in figure 1. Although there are obviously interactions between the factors which affect each branch of the chart, the basic assumption is made that each branch reaches a decision essentially independent of the others. A review of many of the major recent issues in transportation seems to reinforce this assumption.

The work of this project is concerned almost entirely with the Passenger Acceptance Model. Major emphasis is on criteria for vehicle acceptance although the other inputs were treated to the extent that they interact with the vehicle acceptance. This implies a thorough understanding of all the inputs. Without any attempt to be exhaustive, the general content of the various input classes will include items such as the following:

Inputs due to aircraft (vehicle)

motion--6 degrees of freedom (longitudinal, vertical, lateral, roll, pitch, and yaw) including effects of amplitude, velocity, acceleration, frequency, randomness, etc.

cabin environment--temperature, humidity, noise, odors, seat accommodations, spaciousness, etc.

cabin service

visual cues

Inputs due to system characteristics

safety

convenience

dependability

comfort

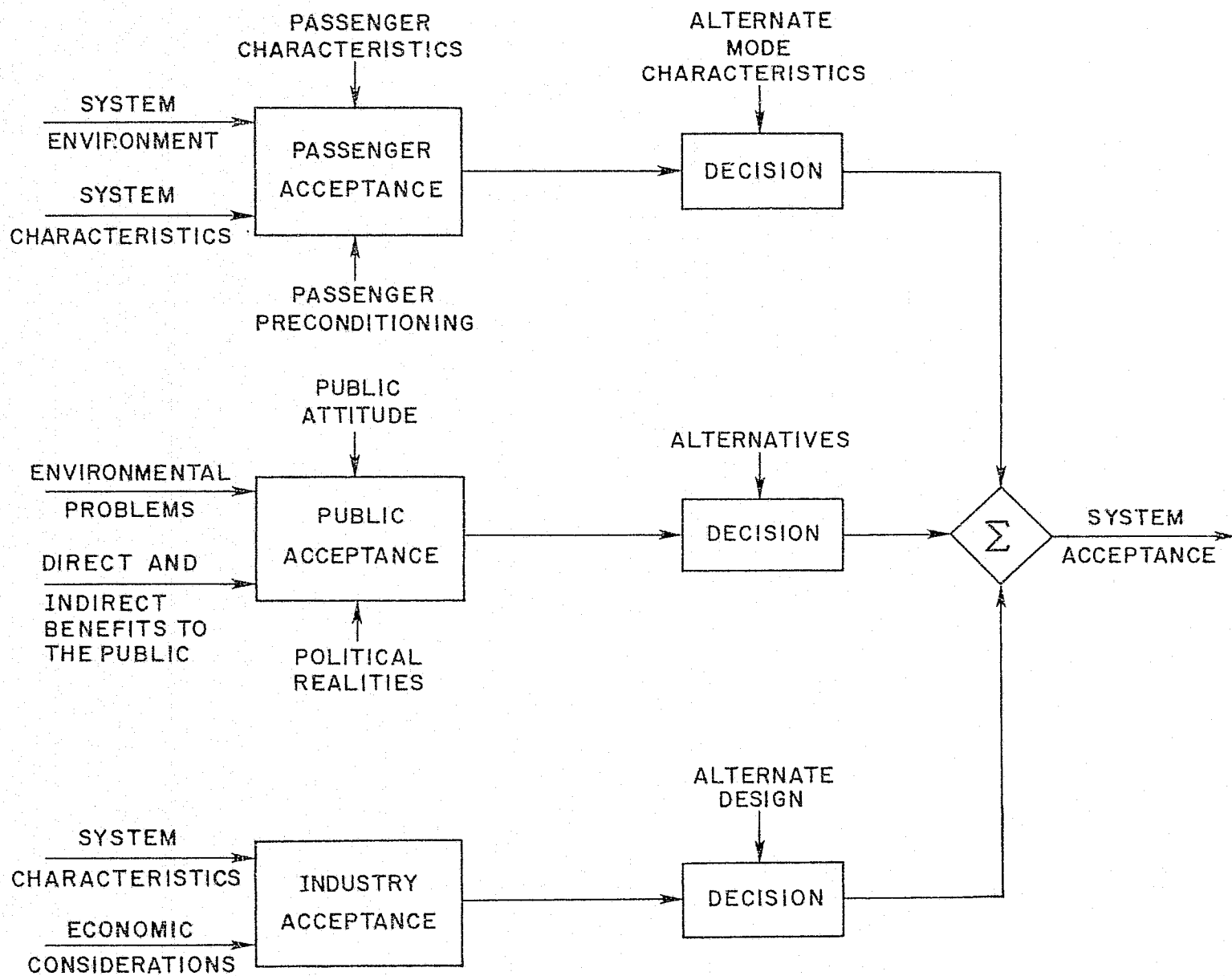


Figure 1. - Problem solution plan.

Inputs due to system characteristics (continued)

time savings	aesthetics
cost	service amenities

Inputs due to passenger characteristics

demographic	trip motivation
economic	flight experience
social	flight attitude

Inputs due to passenger preconditioning

impressions based on marketing and promotion
experiences related to trip--airport access, parking, terminal accommodations and services, aircraft delays, etc.
general physiological and psychological being at time of the trip

As illustrated in figure 1, the focus of the work is on the development of a quantitative model which, when presented with the proper inputs representative of a particular transportation system will account for, or predict as the case may be, the reaction of the passenger. Additionally it will make suggestions for improvements in the system which will enhance passenger acceptance limits for various inputs which could then be utilized by the system designers and planners as criteria which they must meet in their concepts.

The method of approach to achieving the program objectives was structured into the following major phases:

1. Identify the characteristics of the typical air traveler or the distribution of traveler characteristics;
2. Determine the relative importance to the traveler of the various components and features of the total air transportation system;
3. Determine human reaction to the details of the aircraft environment;
4. Develop system acceptance criteria;
5. Test and refine these criteria;
6. Illustrative applications of the criteria.

The work and results of each of these phases will be discussed briefly and summarized in the remaining sections of this report. In addition, the section on related activities (page 23) describes some general activities

undertaken in support of the program as a whole. Figure 2 may be useful to the reader in relating the various activities described in each section to the objectives. It represents what might be called the research strategy for the program.

The basic model which allows one to determine how well an existing or proposed system meets the acceptance criteria has its roots in actual real-life data obtained from an extensive field test program. The components of these field tests included questionnairing and interviewing of both potential and actual passengers in aircraft, in terminals, at home and at places of business, and they included actual commercial flights on a variety of light aircraft in which the reaction of both special test subjects and regular passengers could be related to physical measurements of the aircraft environment.

Since the environmental conditions and passenger characteristics which can be encountered in actual operating conditions are uncontrollable and generally limited in scope or range, they are not necessarily representative of what might be applicable to future systems. Thus it is important to extend the range of the data base from which a model will eventually be constructed. This was done by simulations, both physical, using controllable aircraft and laboratory devices, as well as with the computer. The model itself emerges from a careful and detailed statistical analysis of this data base.

Once the model has been developed, it is important to validate it and understand the restrictions and limitations imposed by the conditions under which it was constructed. This is done by another set of field test situations in which the independent variable terms in the model are measured and the passenger reaction computed. This theoretical reaction is then compared with the actual passenger reaction obtained by questionnaire or interview during the field test.

Of course throughout all of the steps of this process, a careful review of the existing literature is an essential component of the work.

THE CHARACTERISTICS OF THE AIR TRAVELER

The objective of this phase was to document those characteristics of the travelling public which might be expected to influence the attitude of an individual toward air transportation, thus generating a data base essential to the entire program. The data are classified into two major subgroups which are individually important to the program, viz., those individuals who normally fly reasonably frequently, and those who do not.

The following characteristics were identified as constituting a minimal data set:

1. Demographic characteristics (age, sex, income, occupation, education, etc.);

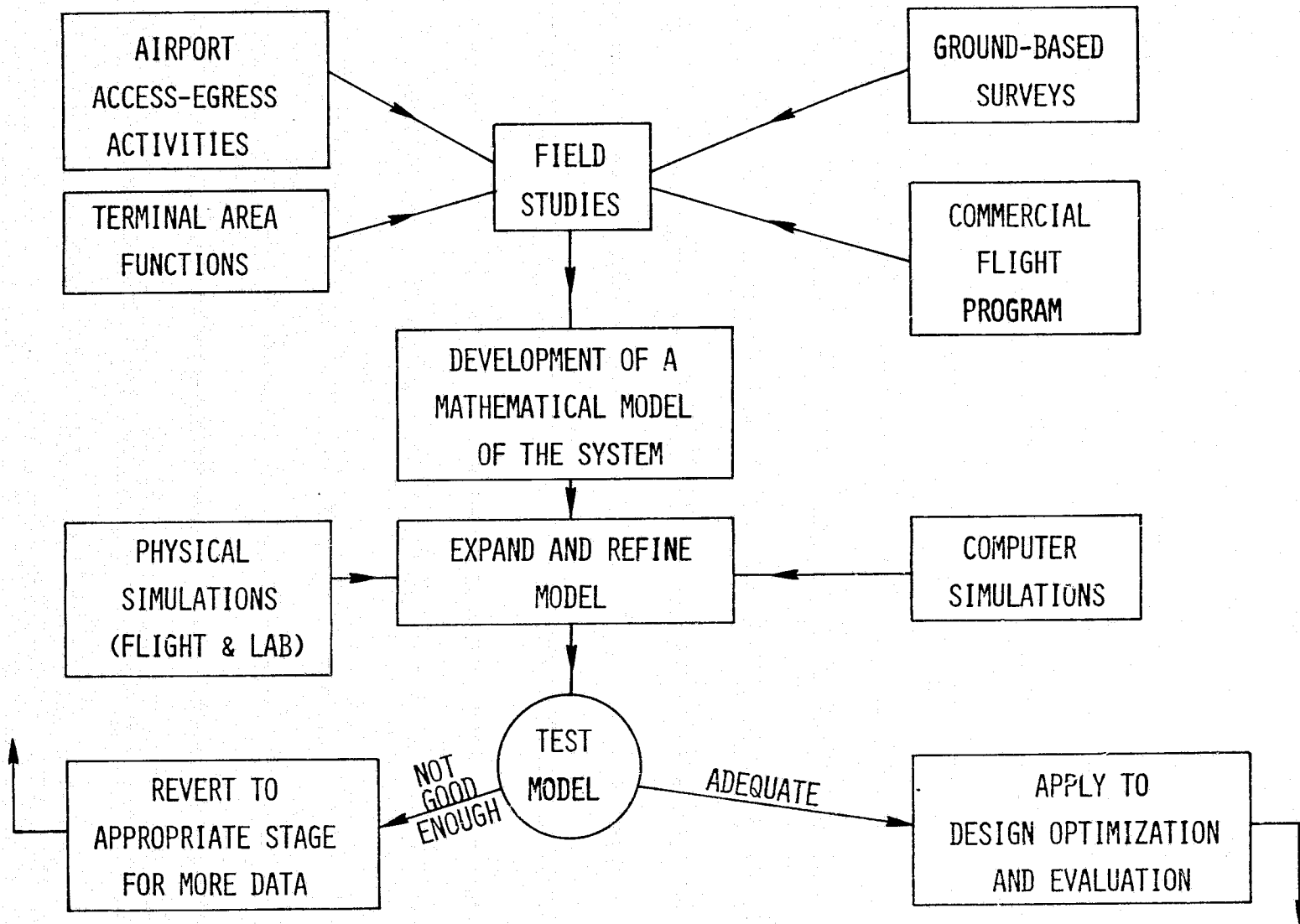


Figure 2. - Research strategy.

2. Trip motivation (frequency and purpose);
3. Personal characteristics (attitudes, preferences, habits);
4. Impressions of air transportation (from experience or from marketing and promotion).

The major efforts relating to this phase are reported in references (1), (3), (4), and (8). Reference (4) contains a detailed analysis of the readily-available literature, while the results obtained from ground-based questionnaires are reported in (1) and (3). Reference (8) summarizes some of the air traveler characteristics encountered in the initial series of flight tests on commercial vehicles. Additional information on the air traveler can be found in many of the other reports, particularly those involved with the work on the importance of system features to the traveler (page 10).

Table 1 presents a general summary of the characterization of the typical air traveler. In this table, the results of two separate in-flight samplings are compared with the trends established in the literature.

THE IMPORTANCE OF SYSTEM FEATURES TO THE TRAVELER

The actual vehicle ride is only a part, and in the case of short-haul air transportation, often not even a major part of the total trip. Thus the other experiences which a traveler has in moving from an initial point of origin to a final point of destination may be of crucial importance. They conceivably affect the traveler's acceptance of the system in two ways: first, the characteristics of each system component can be crucial per se in an acceptance decision; and second, each could contribute to the conditioning of the travelers concerning their acceptance of succeeding components.

In examining system characteristics, it is important to include segments such as terminal access, parking, handling in terminal, transfers at hubs, and terminal egress. Each area should be studied at both the origin and destination ends of the trip, as the service functions to the passenger are different in each case.

The primary characteristics of the transportation system which must be considered at each stage are:

1. safety;
2. dependability;
3. time savings;
4. cost;
5. convenience;

TABLE 1. - CHARACTERISTICS OF THE TRAVELING PUBLIC

	<u>General Travel Surveys (1972)</u>	<u>First In-flight Sample (1972)</u>	<u>Second In-flight Sample (1974)</u>
<u>N</u>	3000+	<u>758</u>	<u>861</u>
<u>Sex</u>			
Male	75%	88%	80%
Female	25	12	20
<u>Age</u>			
20 & under	12	6	4
21-40	40	47	45
41-60	35	42	45
over 60	13	5	6
<u>Education</u>			
College	80	81	N.A.
Noncollege	20	19	N.A.
<u>Occupation</u>			
Executive	60	68	66
Managerial			
Professional			
Technical			
Other	40	32	34
<u>Purpose of Trip</u>			
Business	75	79	72
Other	25	21	28
<u>Income</u>			
Median	\$22,000	\$22,293	\$24,069

Note: N.A. = not asked on this questionnaire.

6. comfort;
7. aesthetics.

As in the characteristics of the air traveler phase, most of the data have been obtained from questionnaire surveys administered in home and office, in flight, and in air terminals. Some data are presented in references (1) and (3), but the major documentation and discussions of this phase of the program are contained in references (7), (14), (18), and (21).

Figure 3 summarizes the evaluations of system features obtained both in flight and on the ground. In addition to giving an insight into the relative importance of the attributes, this figure also illustrates the importance of the method of sampling. Since the responses to the questionnaires represent subjective judgments, the perception of the responder is the dominant factor. Although the general characteristics of the ground-based and in-flight groups are basically the same, the perceptions of certain features are somewhat different when the experience is current as compared to when it was remote (e.g., comfort, cost, and on-board services).

Table 11 shows how these perceptions breakdown according to characteristics of the sample. The data are for the in-flight surveys, but the last column provides a relative comparison with ground-based surveys. The major points of difference are circled. Both women and all travelers engaged in personal travel tend to downgrade the importance of time savings; business travelers and women seem a little more sensitive to their surroundings, as are women to on-board service. However, these differences across the population seem relatively minor when viewed from the overall perspective.

Reference (22) presents some of the work done in an attempt to develop user satisfaction ratings for airports so that this factor could be included into the process of evaluating the satisfaction with the entire trip. The initial step as described in detail in that report was to identify the important factors to be considered in terminal evaluations, and to develop the methodology and procedures for acquiring the data. Unfortunately, the resources available to the project were not adequate to permit the acquisition of the large amounts of field data required to actually develop terminal acceptance models.

When the composite of the questionnaire responses are subjected to standard factor analysis techniques, an interesting pattern emerges. The results indicate that the variables associated with the travelers degree of satisfaction with an air travel experience can be distinguished on the basis of four principal categories or dimensions:

Dimension 1--Safety. This includes reliability or dependability.

Dimension 2--Cost/Benefit. It is interesting to note that cost alone is not the prime quantity involved here; convenience and time saving must be considered in a trade-off with cost.

TABLE 11. - GROUP RESPONSES TO SYSTEM FEATURES

(RELATIVE RANKINGS)

	(RELATIVE RANKINGS)						Attitude Toward Flying		Total Sample Ground-Based Survey
	Total Sample	Sex		Occupation	Purpose of Trip		Love to Fly	Fly Because I Have to	
		All	Male		Female	Prof.,Tech			
SAFETY	1	1	1	1	1	1	1	1	1
RELIABILITY	2	2	2	2	2	2	2	2	2
TIME SAVINGS	3	3	4	3	3	5	3	3	3
CONVENIENCE	4	4	3	4	4	3	4	4	4
COMFORT	5	5	5	5	5	4	5	5	5
COST	6	6	7	6	6	6	6	6	6
SERVICES ON BOARD	7	7	6	7	9	7	7	7	7
ABILITY TO READ	8	8	9	8	8	9	8	8	*
SURROUNDINGS	9	9	8	9	7	8	9	9	8
ABILITY TO WRITE	10	10	10	10	10	10	10	10	*9

*called ability to work in this survey.

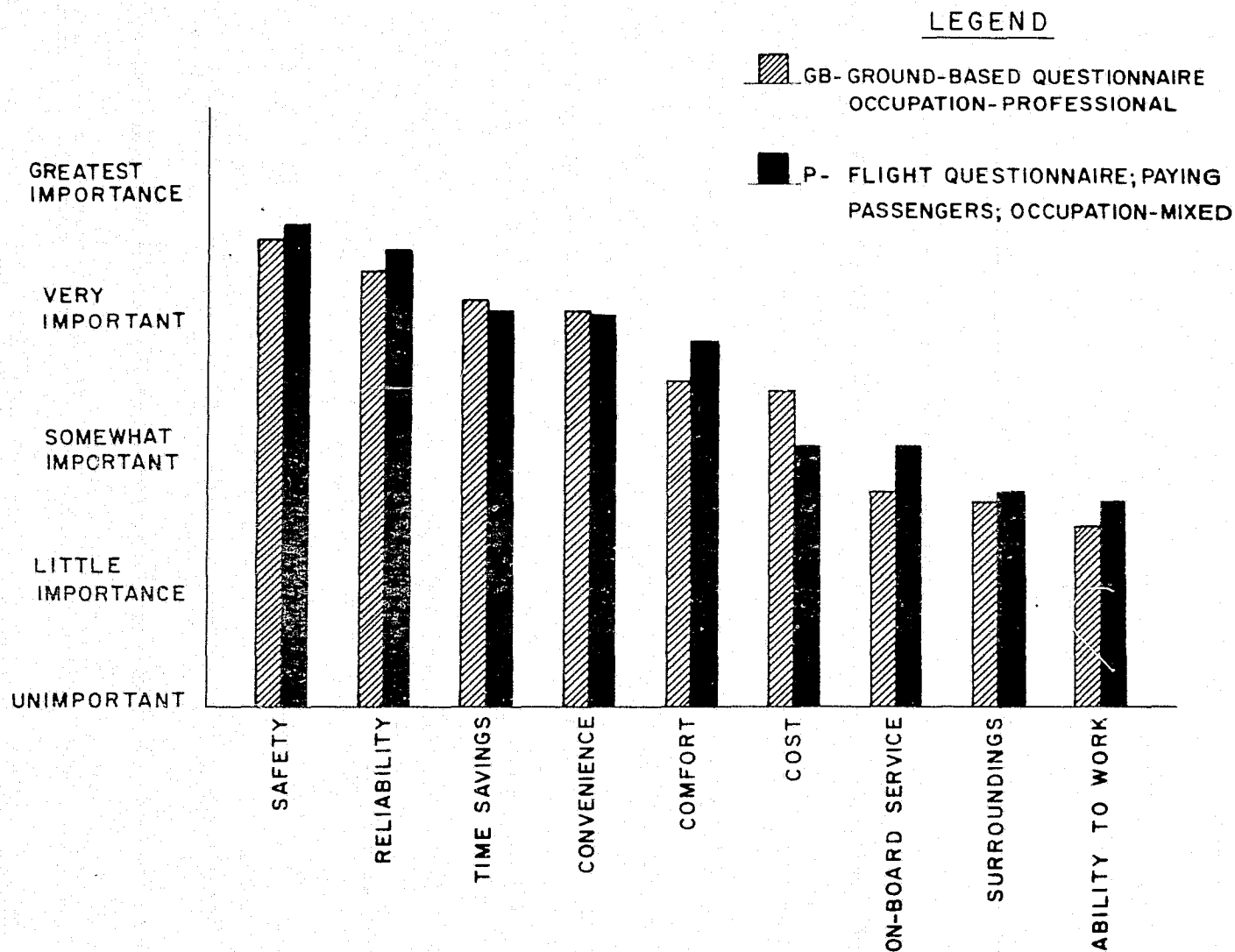


Figure 3. - The importance of system features.

Dimension 3--Luxury. This dimension includes a mix of comfort, convenience, on-board services, and aesthetics.

Dimension 4--On-board Activity. This characterizes the passenger's preference for how to spend the time in flight, and is strongly influenced by comfort.

Thus, the customary variables associated with travel are not unique to a given dimension, but generally appear more than once and often in a different context.

THE TRAVELER'S REACTION TO THE AIRCRAFT ENVIRONMENT

As in the section on air traveler characteristics (page 6), concern must again be given to two special subgroups, those that normally travel by air, and those that do not. In general the aircraft environment must be described by at least the following categories:

1. Motion--six degree of freedom, amplitude, velocity, acceleration, frequency, etc.
2. Other Cabin Variables--temperature, pressure, noise, lighting, odors, etc.
3. Seats--size, type, spacing, etc.
4. Visual Cues--window size, location, flight altitude, day vs. night, etc.
5. Flight Activities--eating, drinking, writing, talking, etc.

The object of this phase was to obtain quantitative expressions of passenger reactions to these variables, while at the same time observing the magnitude of the variables. Such information provides the fundamental elements necessary for modeling the passenger's reaction to the aircraft environment, more tersely described as passenger comfort.

Flight-test programs were conducted with the cooperation of the participating airlines on regularly-scheduled flights of one local-service carrier, four commuter carriers, and one helicopter line. Subjective reactions to comfort and overall trip satisfaction were obtained via questionnaire from the regular passenger; more detailed evaluations were obtained at regularly-scheduled frequent intervals from specially-trained test subjects taken on-board these regularly-scheduled flights.

Special Instrumentation was designed and constructed to measure six degree of freedom motion, temperature, pressure, and noise level at any arbitrarily-selected station in the aircraft. These readings were recorded together with the subjective comfort evaluations of the test subjects. This instrumentation is described more fully in references (6) and (8).

The numerical data and the models which resulted from their careful analysis will be discussed in the next section (page 17). On a more qualitative basis the results obtained from the questionnaires administered to the regular passengers are of considerable interest. Detailed analyses and discussion of the results may be found in references (3), (6), (8), (18), (21), and (25).

Figures 4 and 5 illustrate the essence of the findings. Figure 4 summarizes the perceptions of the passengers concerning the various attributes of aircraft comfort. The almost universal importance of temperature, seating, noise, and motion is clearly shown. It is also interesting to note the differences in perception between the actual passenger, and the experienced traveler reflecting on-flight experiences from the vantage point of home or office. Some attributes like lighting, presence of smoke, and ability to work, which seem so important on the ground, tend to lose their importance once the traveler is airborne. Conversely, the importance of pressure is generally downgraded until the passenger encounters pressure changes in flight.

The rather low esteem granted to the ability to work was somewhat of a surprise. Subsequently, an effort was made to understand how the passenger values activities during the flight. The results are shown in figure 5. In spite of the fact that the passengers were highly oriented toward business and professional types (table 1), the ability to read seems the most essential. Fortunately, this poses much less severe requirements than do other activities associated with work (e.g., writing).

More detailed analysis of the data produced one of the most important conclusions to be drawn from these qualitative observations--the relatively high importance of seating to ride comfort (ref. 18).

THE MODELING OF TRAVELER ACCEPTANCE--RIDE QUALITY CRITERIA

The general approach to developing models of passenger acceptance from which ride quality criteria can be deduced is outlined in the following seven steps, each of which will be discussed briefly.

1. Obtain detailed evaluations of comfort from special test subjects under known (measured) environmental conditions.
2. Obtain an overall evaluation of comfort and trip satisfaction from regular passengers.
3. Relate the test subject results to the results obtained from the regular passengers.
4. Relate comfort evaluations to overall trip satisfaction evaluations.
5. Extend the range of the environmental variables through the use of simulators and special test subjects.

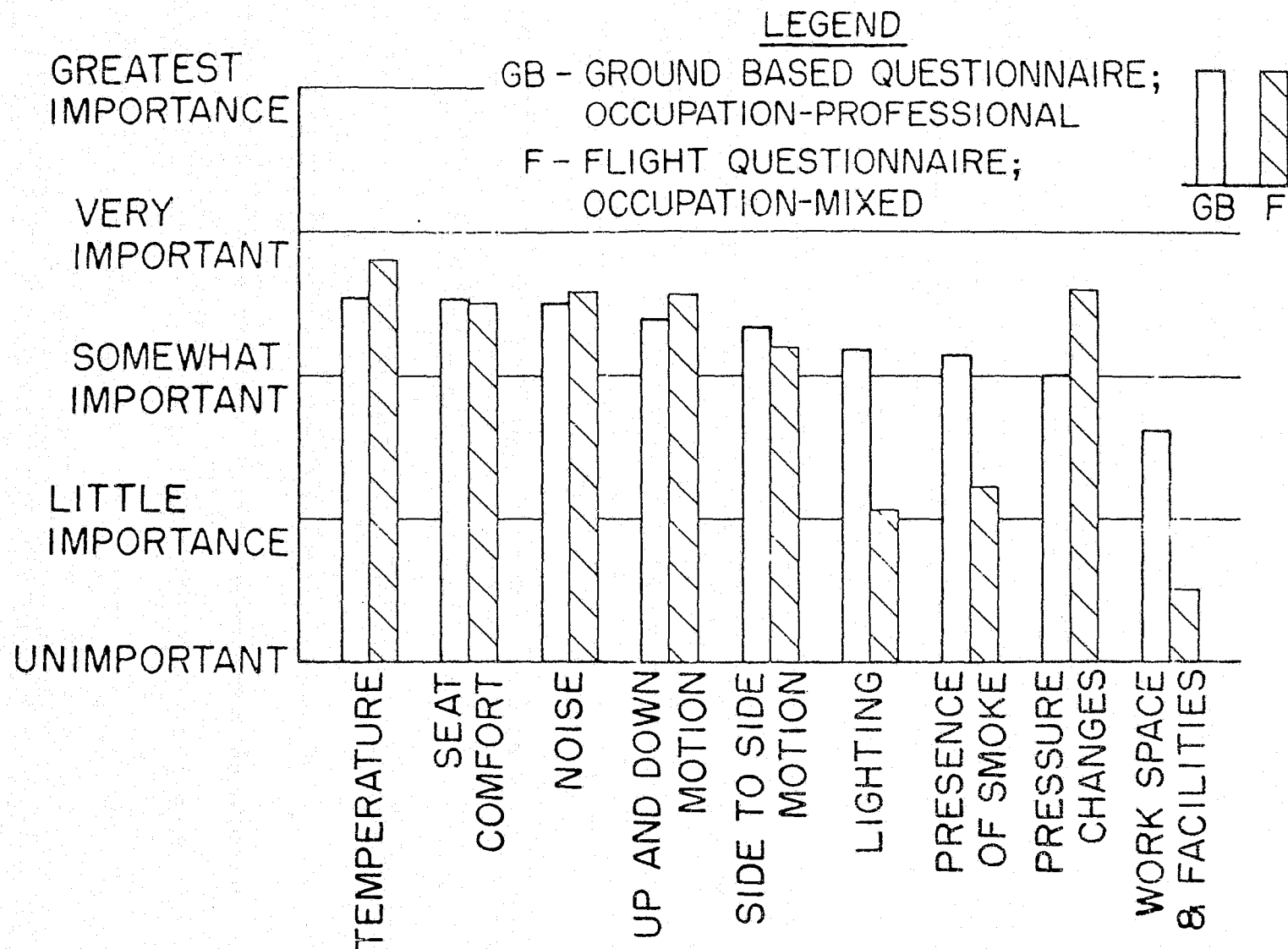


Figure 4. - Factors in determining aircraft comfort.

GROUND BASED QUESTIONNAIRE; OCCUPATION PROFESSIONAL

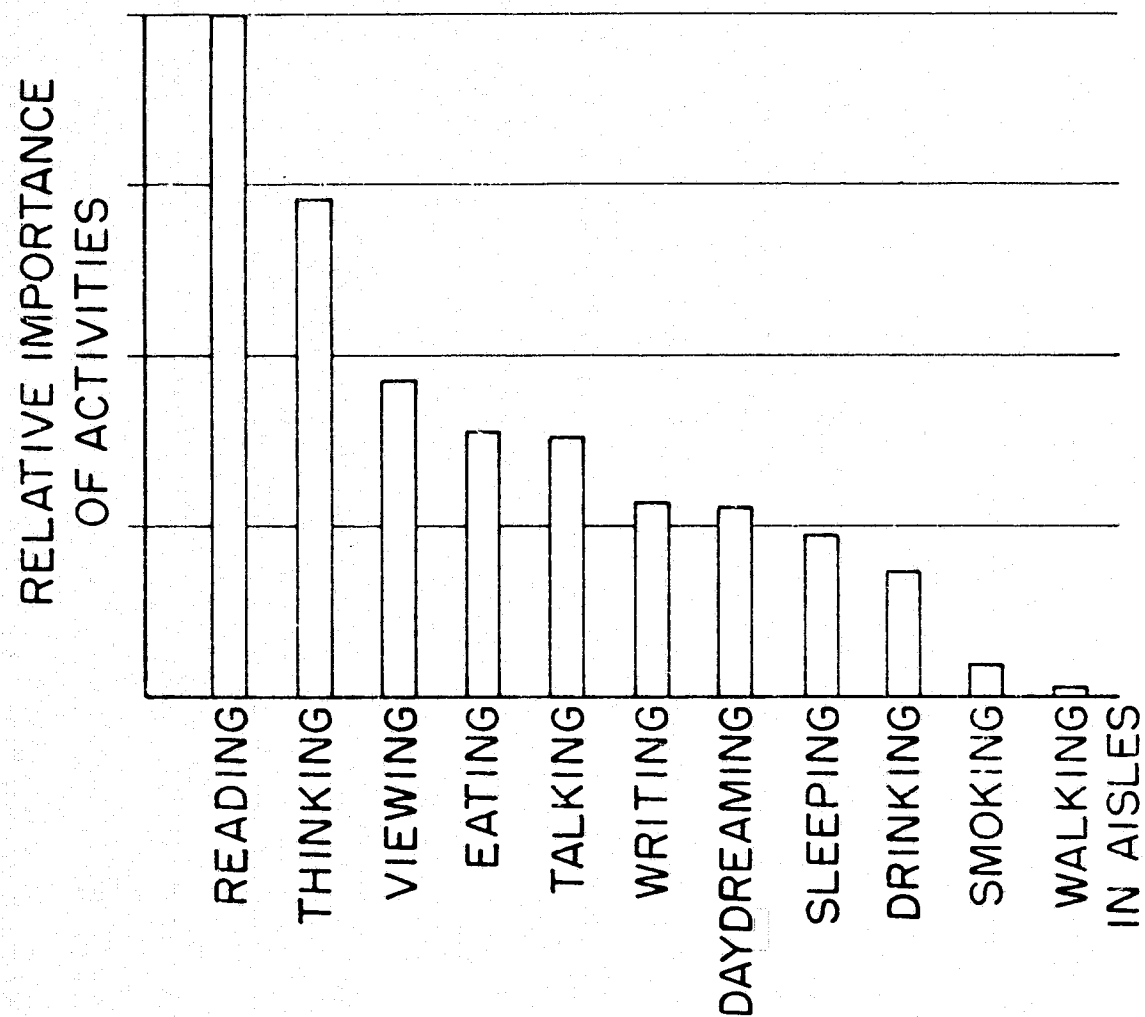


Figure 5. - Importance of in-flight activities.

6. Analyze the data for correlations between comfort ratings and environmental variables.
7. Generate models through regression on the significant variables.

The first two steps are conducted simultaneously on regularly-scheduled flights and have been summarised in earlier sections. The test subject responses are obtained at regular intervals during the flight and are entered as a rating number (basically on a scale of 1-7) on the same tape which is recording the variables which describe the vehicle environment. The responses are based on a similar rating scale obtained by a questionnaire completed near the end of the flight.

Since only overall ratings are obtained from the passengers, but the more detailed information obtained from the test subjects is required for accurate model building, an understanding of the quantitative relationship between these two sets of data is essential to the success of the approach. Fortunately as demonstrated in reference (11) it was possible to deduce a stable relationship between the responses of these two groups.

To potential users of ride quality criteria, the key factor is passenger satisfaction, or desire to take another trip by this mode. However, the quantitative data are based on comfort ratings and so a relationship is required between these two subjective measures. It is possible to develop such a relationship and, as shown in figure 6, it is quite stable. The solid line gives the function as derived from one set of flight experiments, while the dots are values obtained from the analysis of the results from another set of experiments. Details of the development of this relationship can be found in reference (21).

Since the values of environmental variables encountered in regularly-scheduled commercial flights are random and considerably limited in range, it was necessary to resort to motion simulators in order to extend the range of the motion variables. The fact that test subject responses had been shown to be transferrable to passenger reactions made the concept of simulation workable, but the actual validity of data obtained from readily available and relatively inexpensive laboratory simulators needed to be established. This was successfully accomplished by comparing the results obtained from a carefully executed set of experiments on an in-flight simulator with those observed when the same subjects were exposed to the same sets of motions in the laboratory. The in-flight simulator was a special aircraft in which a variety of pre-selected motions could be generated in flight. These experiments and the results are well documented in references (13), (17), and (20).

As mentioned earlier, the modeling process was based on regressing the significant variables with the subjective evaluation of comfort. The basic model was thus a comfort model. The overall process of model development is best described in references (16) and (31), while a catalog of the data used is compiled in reference (12).

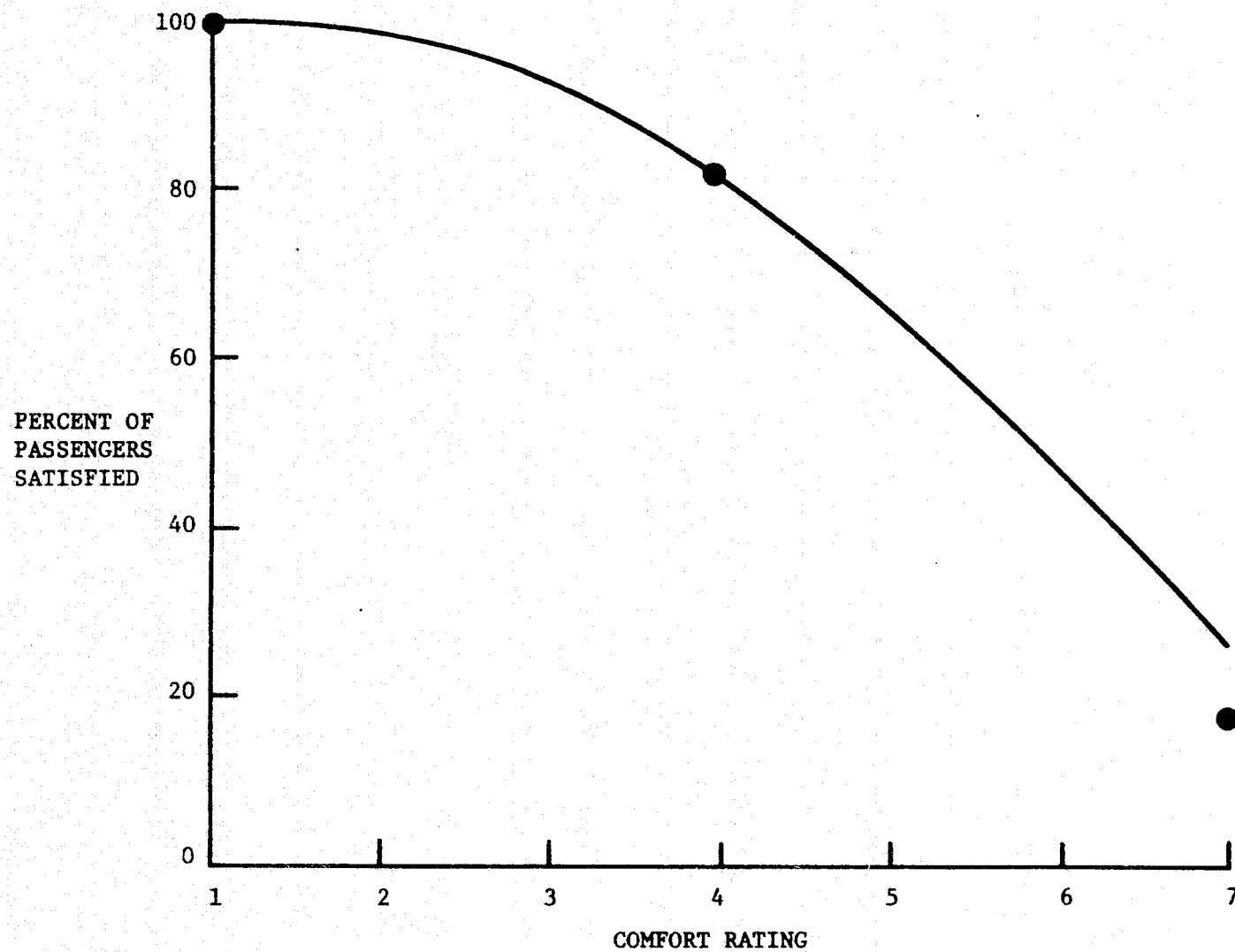


Figure 6. - Relationship of passenger comfort to passenger satisfaction.

With regard to the effect of motion on comfort, four general types of models are explored: a simple linear regression, regression with exponential terms and cross products, both using RMS accelerations as the independent variable, a power spectral density analysis, and a hybrid concept in which comfort was related to the RMS values of acceleration in discrete octave bands. The results show that the linear regression model, although not the "best" in a statistical sense is sufficiently close to representing actual events so that further sophistication hardly seems warranted. Similarly, for most applications to aircraft, a simplified version depending only on vertical and transverse RMS accelerations seems adequate. This assumes that the vehicle design is not altered to accentuate some motion component not now present to any appreciable extent.

The actual comfort model recommended for most applications is:

$$C = 2 + 18.90 a_V + 12.1 a_T; \quad a_V > 1.60 a_T$$

$$= 2 + 1.62 a_V + 39.8 a_T \quad a_V < 1.60 a_T$$

where

a_V = RMS acceleration in the vertical direction

a_T = RMS acceleration in the transverse direction.

Figures 7 and 8 illustrate two of the ways in which the results obtained from the model can be presented. In figure 7 the model is used to plot contours of equal comfort, providing information on the trade-offs possible to between vertical and transverse motion, e.g., any point in the space below $C < 3.5$ will provide a ride with a comfort level of 3.5--a generally acceptable level; similarly any point to the right of this line will tend to give a ride quality which is generally unacceptable.

Figure 8 illustrates how the passenger acceptance function can be used. Based on motion values measured at various altitudes over mountainous terrain, it can be seen that the model predicts a 45% probability for providing a satisfactory ride to 85% of the passengers at 152 meters altitude, while at 3048 meters this probability rises to 84%.

With the assistance of work done in other grants from NASA (see page 25), it has been possible to extend these quantitative models to include variables other than motion. The final results are summarized in reference (30). Actually the mean subjective comfort rating for any given set of circumstances (ride situation) is the maximum value provided by any of three separate rating groups, since there appears to be little additive or cross coupling effects between these three groups. They are as follows:

environmental group--motion, noise, temperature, and humidity;

vehicle maneuver group--turns, pitchover, descent or climb, or compound maneuver;

seating and spacing--width between armrests, and legroom.

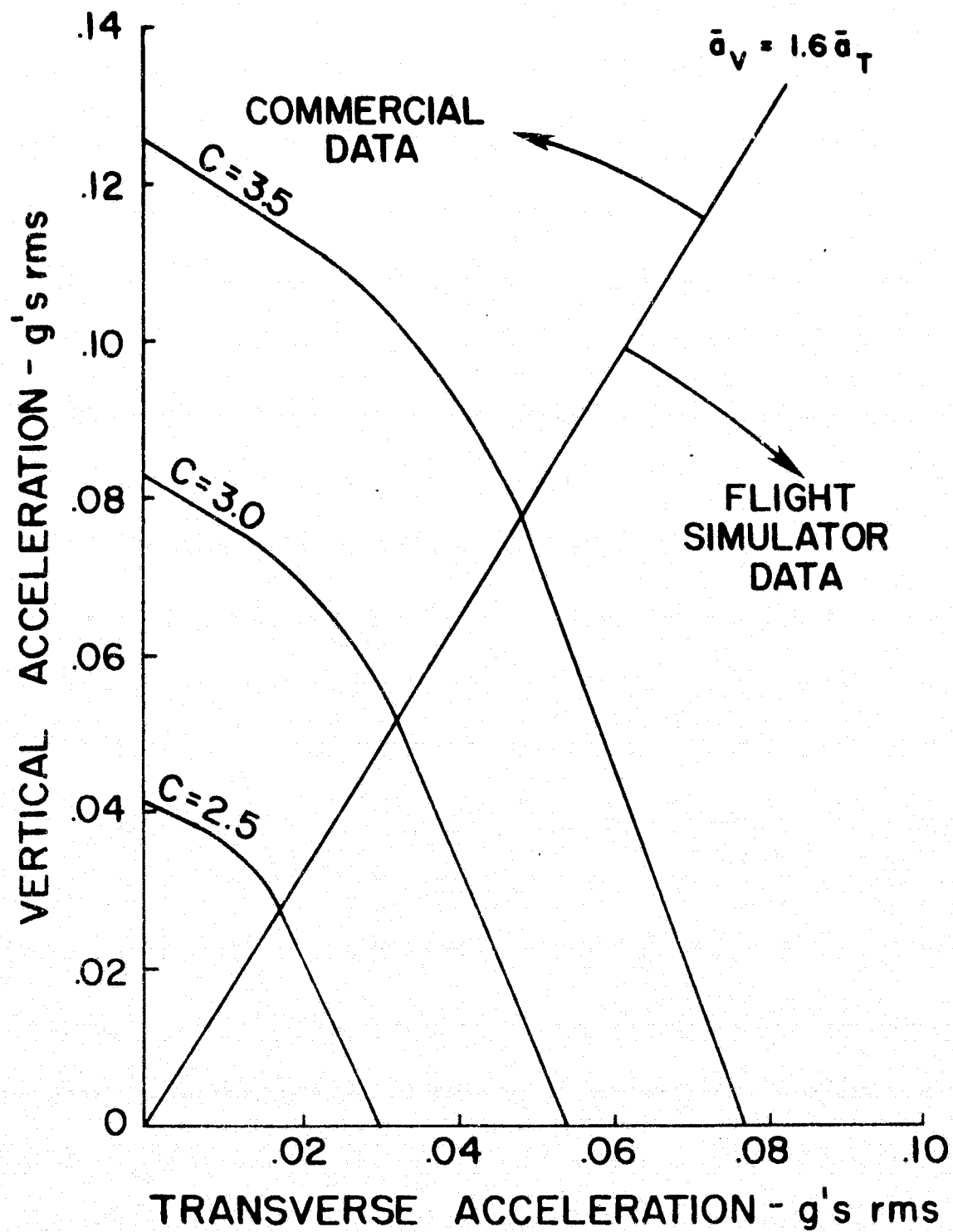


Figure 7. - Iso-comfort contours.

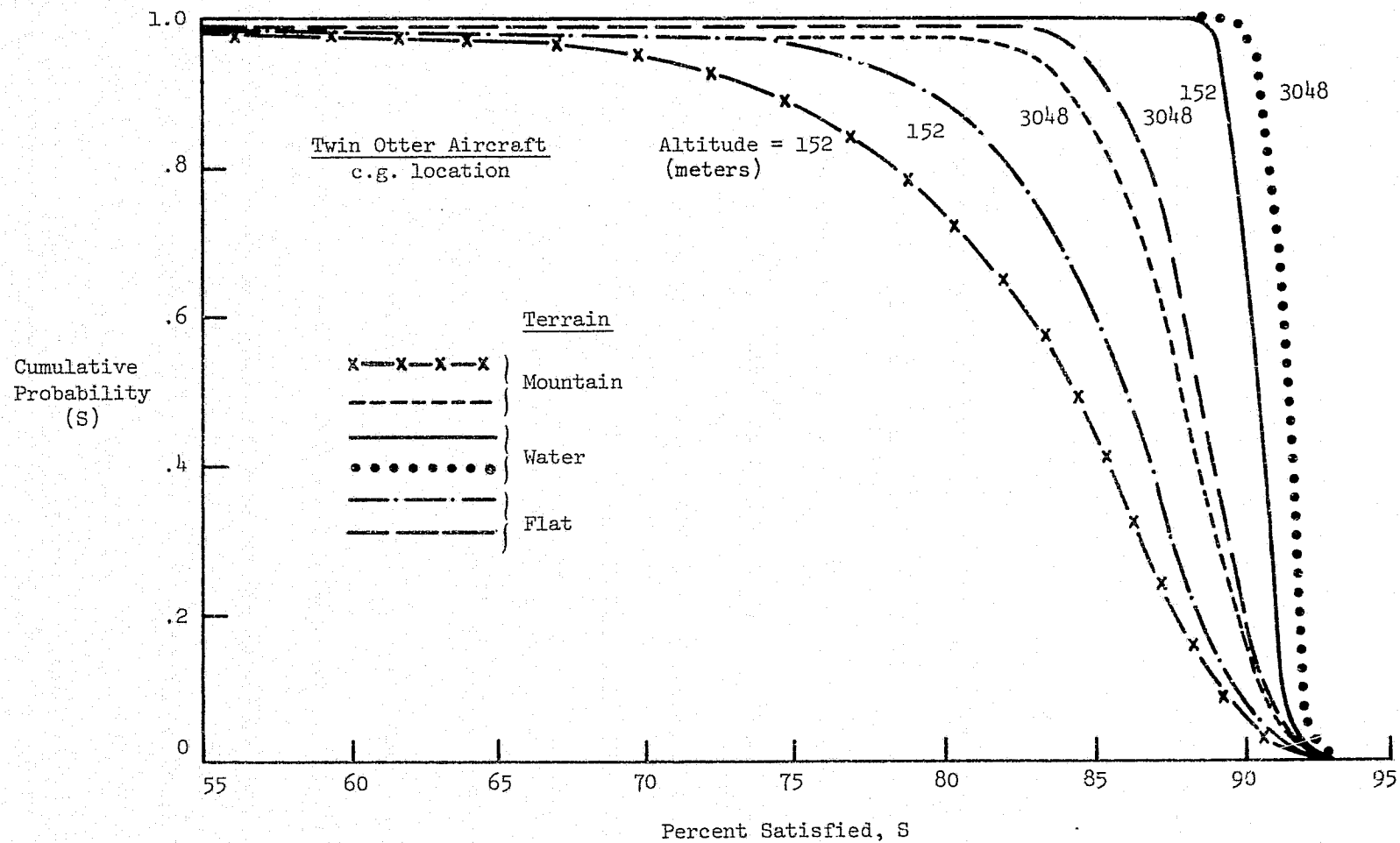


Figure 8. - Satisfaction probability distribution.

Thus

$$C = \max(c_{\text{env}}, c_{\text{man}}, c_{\text{seat}})$$

where numerical expressions have been developed for each of the independent group ratings.

MODEL VALIDATION

A direct approach was used for model validation. Passenger reactions were sampled on a series of regularly-scheduled commuter airline flights using a deHavilland DHC-6 Twin Otter aircraft. The vehicle environment was also measured in the usual manner. The environmental variables were then used to compute the expected level of comfort from the model. The results from these computations were then compared with the actual passenger responses and found to be in good agreement. These validation tests are described in reference (27).

As described in this reference, a further check on the validity of the model was made by applying it to a situation in which it might be expected not to apply. A good opportunity arose in connection with the Airtransit experiment operated by the Canadian Ministry of Transport to provide city-center STOL transportation between Montreal and Ottawa (27). Again, a Twin Otter aircraft was used, but with reduced seating capacity, providing larger, more comfortable seats and legroom. There were also other improvements including improved air-conditioning and many aesthetics. In this case the model, using motions measured in the aircraft predicted an acceptance level somewhat lower than that observed. This was as expected, since the data upon which the model was developed did not represent conditions as good as those provided by Airtransit.

APPLICATIONS

As indicated earlier, there are two principal uses for the model. The first is to evaluate the acceptance of existing equipment, operating procedures or entire systems. The second is to predict what acceptance might be for proposed designs or procedures which are not yet available for trial or observation.

Several applications of the first type are summarized in reference (30). All that is required is to measure the observed environmental variables and then compute the predicted comfort or satisfaction as the case may be. One case reported above was the effect on ride quality caused by using uprigged spoilers on a 747 to reduce trailing vortices (see also reference (23)). In another case the effects of a variety of maneuvers required by proposed landing and approach patterns in the terminal area were evaluated.

In the second category a general computational approach was devised. This is illustrated in figure 9. In the case of aircraft, the inputs to the vehicle are forcing functions such as turbulence spectra or wind gusts, and planned operational trajectories or flight paths. Although the turbulence must be estimated, it is usually possible to write a mathematical relationship describing these forcing functions, at least in a probabilistic sense. These inputs are imposed upon the aircraft transfer, or response, functions, which in turn are dependent upon the aerodynamics and mass properties of the vehicle, and are readily available in the literature for many aircraft. The combination of these two mathematical relationships enables one to compute the probable motions throughout the aircraft. Typical values can be added for the other environmental variables and the comfort and satisfaction models applied in the usual fashion. Reference (30) discusses how this might be applied to deduce the effects of changes in aircraft wing loading on ride acceptance; while reference (24) uses this approach to estimate the relative ride acceptance of several different aircraft in the same turbulence field. The details of the computations are described in reference (31).

RELATED ACTIVITIES

Symposia and Workshops

A very important aspect of the work under this grant was to keep abreast of other activities in the areas related to ride quality. To this end we contributed to the 1972 Symposium on Vehicle Ride Quality organized by and held at the Langley Research Center in July of 1972, both through a formal presentation (5) and through representation on discussion panels. Following this meeting a small group began to meet informally under the auspices of NASA/Langley to review and discuss matters of interest to the ride quality community. The principal investigators, and on occasion members of their staff, maintained an active participation in this group.

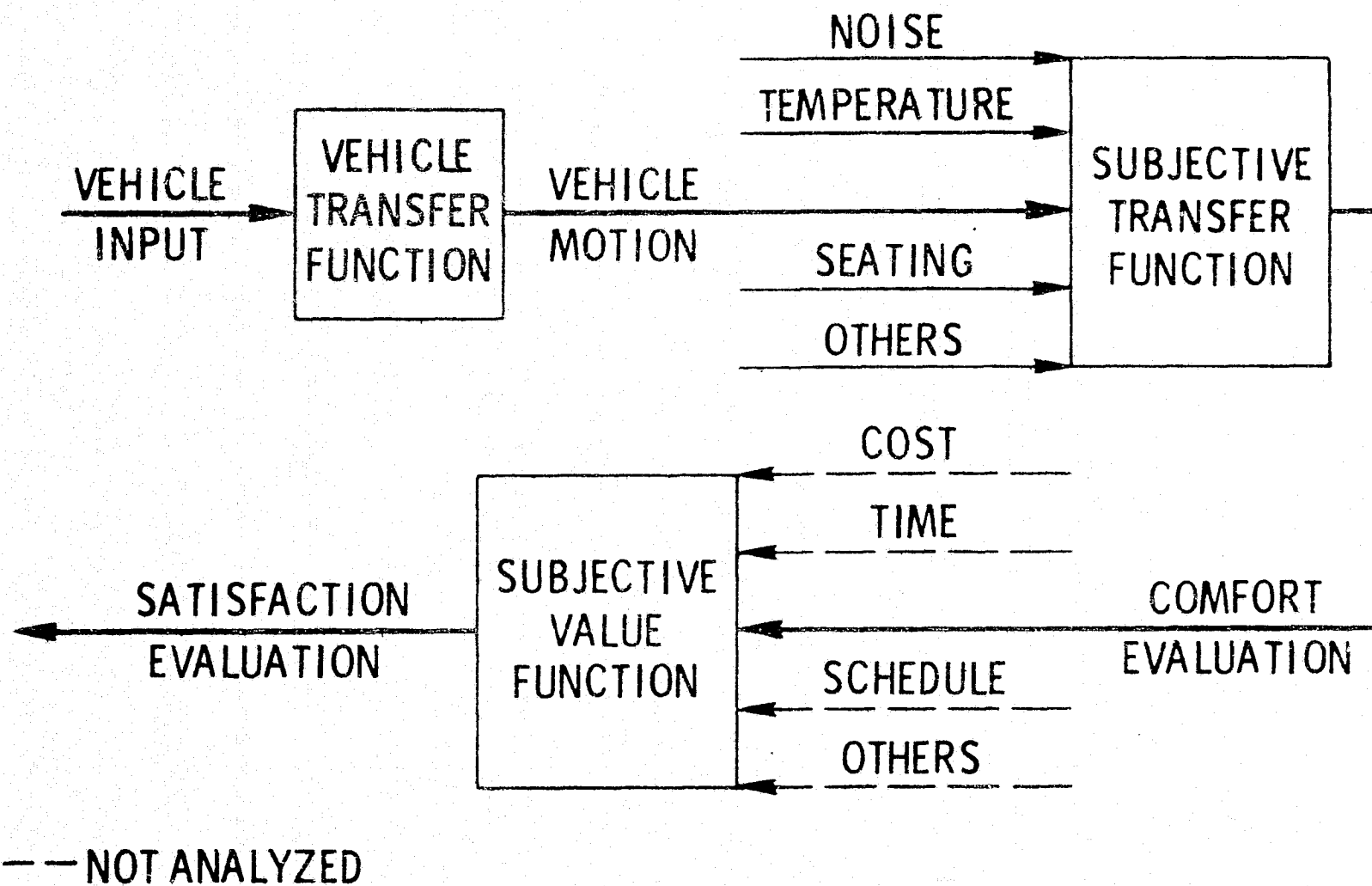


Figure 9. - A system model for determining passenger satisfaction.

By early 1975 it was obvious that research in the field of ride quality had progressed to the point where another symposium was in order. It was also determined that the focus on the important issues could be improved by organizing a limited-participation workshop to digest the implications of the work reported at the symposium, and place it in its proper perspective. Under the sponsorship of this grant, the University of Virginia accepted the responsibility for the general organization and conduct of the symposium and workshop, which were held in Williamsburg, Virginia, in August of 1975. The Proceedings of the symposium were published jointly by NASA and DOT.* The intent of the workshop was to summarize the state-of-the-art of knowledge relating to the various aspects of ride quality. The report of these activities was assembled and edited as a task assigned under this grant (35).

At the time of the 1975 workshop, it was agreed that this experience should be repeated the next year with the objective of using the state-of-the-art summaries as a point of departure for a careful analysis of the major technology gaps which exist in the ride quality field, and the definition of the research tasks required to fill these gaps. Again the University of Virginia agreed to accept the responsibility under this grant for the organization and operation of the 1976 symposium. In addition we agreed to provide professionally-qualified recorders for each of the discussion groups. These recorders prepared summary reports of the deliberations of their respective groups, which were then edited into a single report (32).

Other Research Grants and Contracts

During the period covered by the subject grant four other grants or contracts were active which were closely related to the question of vehicle ride quality, and which either contributed to or drew upon the results of this program. These relations will be discussed briefly in the following paragraphs.

The first involved the establishment of a relationship between the passenger ride quality and the vehicle handling qualities for the pilot.** As shown in figure 10, regions exist where both criteria can be successfully met. Similar regions exist for other values of the flight control parameters. This work was done using both the University of Virginia's Analog Flight Simulator (fixed base) and the Visual Motion Simulator at the Langley Research Center.

Some of the flight data, especially at extreme points, was obtained from a related program supported by the NASA/Flight Research Center (now Dryden Center) at Edwards, California.*** These were obtained using their specially-modified JetStar aircraft known as the General Purpose Airborne Simulator (GPAS).

*NASA TM X-3295, DOT-TSC-OST-75-40.

**NASA Grant #NGR 47-005-208, "The Effects of Aircraft Design on STOL Ride Quality," NASA/Langley Research Center.

***NASA Grant #NGR 47-005-202, "Application of Active Controls Technology to Aircraft Ride Smoothing Systems," NASA/Flight Research Center.

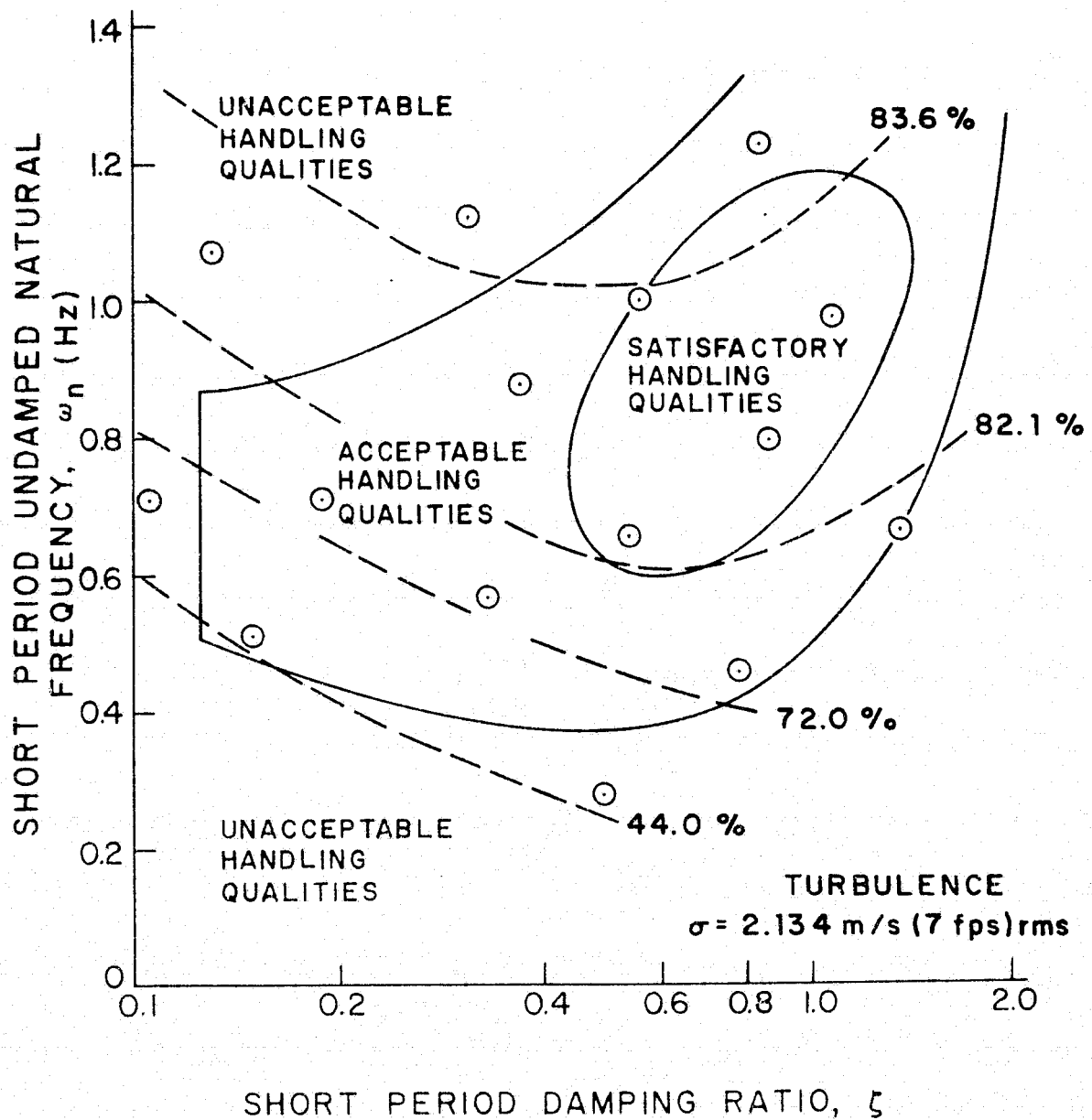


Figure 10, - Ride qualities vs. handling qualities.

(Percentage figures represent contours of equal passenger satisfaction.)

Considerable work on the effect of noise on comfort and passenger acceptance was done both under the subject grant and under a separate grant from the NASA/Langley Research Center.* The effect of noise is indeed significant as can be seen from figure 11. This shows a series of points where the motion was not significantly different, but where noise levels did vary over a range of 16 dB(A). The trend is clear and, as can be seen, this magnitude of change in noise level can affect the comfort level by as much as 2 units on the total scale of 7 units.

This work involved a detailed analysis of the noise problem resulting in good quantitative models. A typical model based on noise levels was reported in reference (30). Improved models based on noise types as characterized by the quantities of noise emanating from the principal aircraft sources of noise will be reported in a doctoral dissertation to be submitted to the Department of Engineering Science and Systems at the University of Virginia by Mr. Ashok N. Rudrapatna during the summer of 1977.

Finally, it should be noted that in cooperation with Dunlap and Associates of Darlen, Connecticut, the techniques and methods developed under this grant have been applied to develop comfort and satisfaction models for passengers using Intercity rail and bus. This work was supported by the Transportation Systems Center of the U.S. Department of Transportation** and the final reports (three volumes) were delivered to the sponsor in June 1977. They should be released soon.

CONCLUSIONS AND RECOMMENDATIONS

The following statements appear to be valid conclusions to be drawn from a review of the activities of the grant:

1. Ride quality is an important variable affecting the decision of users of air transportation.
2. The effect is more important for business travelers than for others; this is significant because business travelers constitute a very large segment of the air transport market.
3. Ride quality on aircraft is influenced by several environmental parameters--especially motion, noise, pressure, temperature, and seating.
4. Models have been developed which quantify the relationship of subjective comfort to all of these important environmental parameters.

*NASA Grant #NSG 1180, "Interior Aircraft Cabin Noise: Impact on Passengers," NASA/Langley Research Center.

**Contract #DOT-TSC-1090, "Developments of Techniques and Data for Evaluating Ride Quality, Dunlap and Associates, Inc.

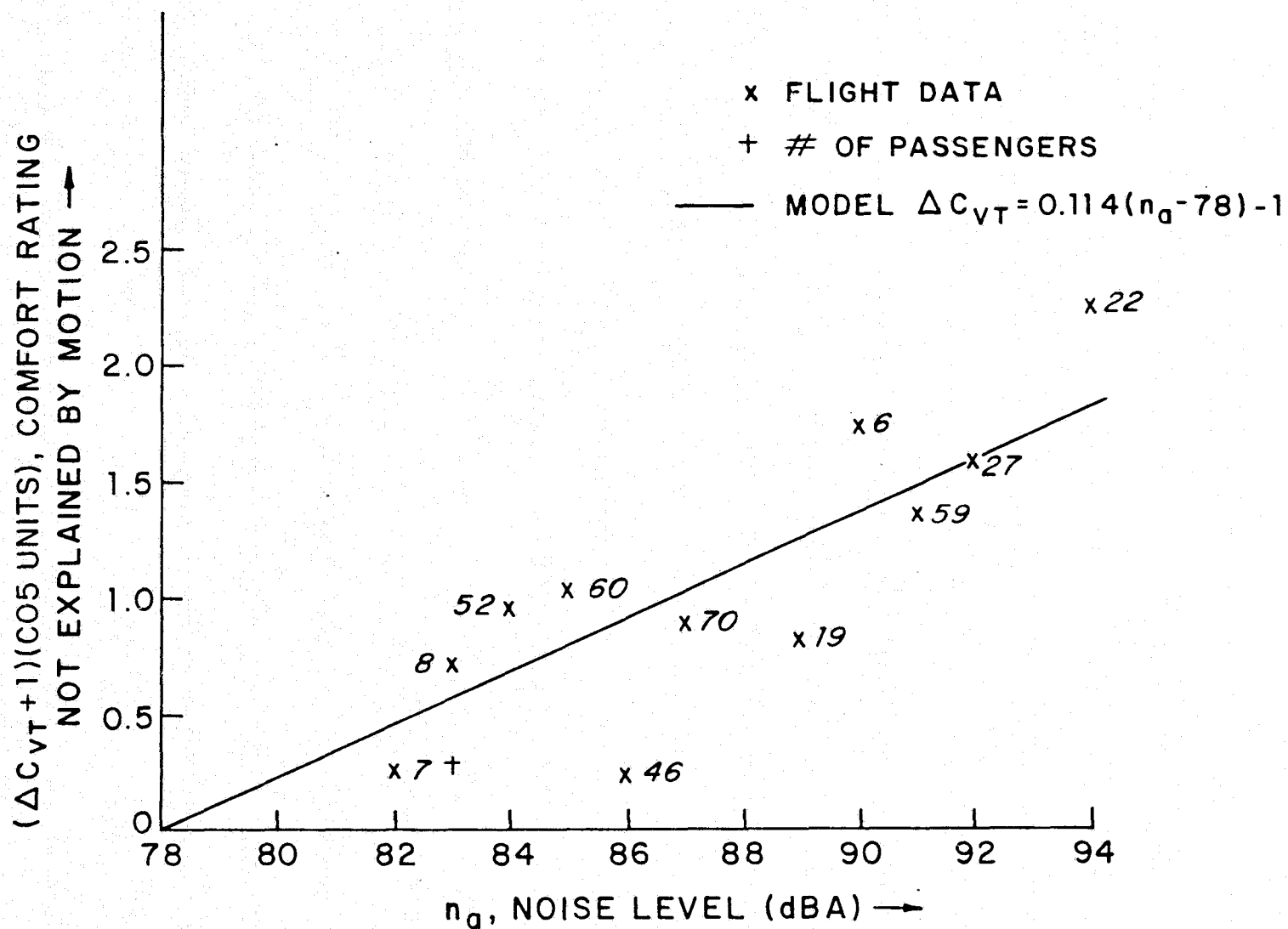


Figure 11. - Effect of noise on comfort rating.

5. Judgments of comfort with regard to inputs from seating, flight paths (maneuvers, turns, etc.) and general environmental stimuli (motion, noise, temperature, and pressure) are independent, with the most uncomfortable influence being the overriding factor.
6. Vertical and transverse accelerations are the dominant motion variables affecting comfort on aircraft.
7. Passenger satisfaction is strongly related to ride quality.
8. A model of passenger satisfaction as a function of passenger comfort has been developed.
9. A computer program to assess the comfort and satisfaction levels of passengers on aircraft subjected to arbitrary flight profiles over arbitrary terrain has been developed.
10. Trade-off studies of the effects of level-of-motion and level-of-noise on comfort in aircraft design have been made.
11. Effects of aircraft design changes on ride quality and passenger satisfaction have been evaluated.
12. A model of the manner in which passengers integrate isolated segments of a flight to obtain an overall comfort rating has been deduced.
13. A test methodology for modeling the ride quality of any mode of transportation has been established.
14. Reliable instrumentation to measure the important environmental variables of any type of vehicle has been developed.
15. A relationship between the subjective evaluations obtained from trained subjects and from regular passengers has been established.
16. It has been shown that other system variables (most notably, convenience) have an effect on passenger satisfaction with the overall trip.
17. A method for assessing the influence of other links (e.g., access, terminal conditions, etc.) in the overall passenger trip has been established.

On the basis of these conclusions, the following recommendations appear to be appropriate:

1. In the interest of improving the acceptability and hence use of public transportation, the techniques developed under this grant should definitely be applied to all modes, particularly at the time that vehicle and system design concepts are being developed. It may be necessary to improve the understanding of modal choice criteria.
2. Further modeling work should be undertaken to better quantify the effects of noise, temperature, and seating.
3. Additional work should be done to include effects of passenger preconditioning in the models. Among the first factors to receive attention should be the land-side activities in air terminals including airport access and egress. Also of importance are the airside procedures in the terminal area including on-board ground delays, holding patterns, etc.
4. The understanding of the passenger decision process has now reached the point where it is important to extend the work into the public and private industry sectors (see figure 1). The objective of the initial step in this regard should probably be to advance these other sectors to the point where the principal interactions or conflicts between all three can be defined.
5. Since most of the data obtained during the present grant involved short-haul transportation, the concepts should be tested in long-haul and intermediate-haul situations.

APPENDIX

Publications

- 1.* JACOBSON, Ira D.
Study of Travel Habits, Attitudes and Preference of Short-Haul Travelers,
Part I--Air Travel by Professional Academic Community
Short-Haul Air Transportation Program Memorandum Report 403201
December 7, 1971

Synopsis

A preliminary analysis is presented of the results obtained from a questionnaire sent to 300 faculty members and administrators at the University of Virginia to ascertain the relative importance of the factors which influence a traveler's evaluation of the acceptability of air transportation. Information is obtained and discussed in five specific areas:

- (1) general passenger identification (demographic, motivational, attitudinal, and past experience data);
- (2) perceived importance of the factors which determine passenger satisfaction with air travel (safety, dependability, convenience, cost, time savings, comfort, terminals, on-board service, ability to work);
- (3) perceived importance of the factors relating to passenger comfort (temperature, seat comfort, noise, lighting, up-down motion, side to side motion, pressure changes, presence of smoke, work space and facilities);
- (4) perceived importance of the ability to engage in various in-flight activities (reading, thinking, viewing, eating, talking, writing, sleeping, drinking, smoking, walking);
- (5) passenger evaluation of the status of current air travel, vis-a-vis satisfaction, comfort, and activities.

It is shown that the results of this survey correlate reasonably well with the results of a limited number of other surveys on similar aspects of passenger satisfaction which are known to exist.

2. JACOBSON, Ira D.
Criteria for Ride Quality--Motion
Short-Haul Air Transportation Program Memorandum Report 403202
February 1972

*Number refers to reference number given in the main text of the report.

Synopsis

The purpose of this memorandum is two-fold: first, to document and review a selected portion of the literature concerned with determining human response to motion; second, to summarize this prior work to formulate the most appropriate criteria for acceptable motion levels which might serve as a preliminary basis for specifications for a first-generation STOL aircraft.

One hundred fifty-two (152) articles are included in the bibliography, these having been selected from over 500 receiving preliminary scrutiny. In order to provide the reader with a quick reference guide to those reports and papers concerned with a particular aspect of human response to motion environment or type of approach, these are classified into the following categories:

- (1) task performance;
- (2) physiological response;
- (3) biomechanical response;
- (4) psychological response;
- (5) review articles;
- (6) theoretical articles;
- (7) laboratory tests;
- (8) field tests.

A tabular summary is also presented of the laboratory and field testing that has been done to study subjective response to motion environments, and a brief analysis of some of the major review articles which have been concerned with subjective response to motion is included.

Tentative acceptance criteria are proposed for vertical, lateral, and longitudinal motions.

3. JACOBSON, Ira D. and MARTINEZ, John
The Comfort/Satisfaction of Air Travelers--Basis for a Descriptive Model
Short-Haul Air Transportation Program Memorandum Report 403203
March 1972 (Also: Human Factors, vol. 16, no. 1, pp. 46-55, 1974.)

Synopsis

Data on the passenger acceptance of air transportation obtained from members of the faculty and administration at the University of Virginia via questionnaire (see entry no. 1) are analyzed in detail to ascertain whether they contain the basic properties essential for the formulation

of a descriptive model. Particular interest is focused on two issues: first, an assessment of the relative importance of the various global aspects of the flight environment; second, a determination of regularities within the data across various groups of subjects.

Standard statistical procedures were used to perform analyses compatible with two very different assumptions regarding the underlying attitude structure of the experimental population and the form of the data obtained. A factor analytic approach was applied to the questionnaire data, yielding stimulus configurations based on an assumed linear and metric model. Then interviews were conducted with a randomly-selected sample of the test population, during which paired comparison data were obtained concerning the same variables. These data were analyzed without making linear or metric assumptions.

The results indicate that it does appear feasible to formulate a descriptive model based upon data obtained in this manner. In particular it was found that both comfort and satisfaction can be represented as a four-dimensional composite of commonly-encountered variables.

4. LEE, Wendell and JACOBSON, Ira D.
Characteristics of the Air Traveler--A Selective Review
Short-Haul Air Transportation Program Memorandum Report 403204
June 1972

Synopsis

Over 80 documents from the open literature dating back to 1965 were reviewed for data concerning air traveler characteristics. Although little or no information was found concerning West Coast travelers, it was possible to construct distributions of 6 different demographic characteristics* for 10 East Coast metropolitan areas ranging in population from 17 million to 160,000. In most cases the size and type of the market does have an influence on the characteristics of the air traveler. Thus the passenger acceptance of a given service pattern may have a strong dependence on the market area to which the service is to be applied.

A bibliography of the documents included in the survey is included.

5. KUHLETHAU, A. R. and JACOBSON, I. D.
Investigation of Traveler Acceptance Factors in Short-Haul Air Carrier Operations
Short-Haul Air Transportation Program Technical Report 403205
July 1972 (Also: Proceedings, NASA Symposium on Vehicle Ride Quality, Langley Research Center, July 6-7, 1972, NASA TM X-2620, October 1972, pp. 211-228.)

*occupation, income, trip purpose, age, education, sex.

Synopsis

The initial attempts to deduce a mathematical model of vehicle ride comfort based on actual flight data are presented. The responses of a selected group of test subjects are correlated with direct measurements of actual vehicle motions in six degrees of freedom. A total of 100 flight segments were flown aboard three different aircraft (YS-11, F-227, and B-737) for a variety of turbulence conditions over both flat and mountainous terrain.

Three different approaches for modeling were considered: a simple linear regression on the RMS accelerations in each degree of freedom, a power-spectral density analysis, and a hybrid concept in which comfort is related to the RMS values of acceleration in discrete octave bands. Numerical expressions providing a good representation of the data are presented for the first two. They are in agreement in predicting that the vertical component of acceleration is predominant in affecting the comfort of the passenger.

A review is also presented of the general methodology of the research program, and the characterization of the traveling public obtained from questionnaires (see entries 1 and 3).

6. JACOBSON, Ira D. and KUHLETHAU, A. Robert
Determining STOL Ride Quality Criteria--Passenger Acceptance
Journal of Aircraft, vol. 10, no. 3, March 1973, pp. 163-166.

Synopsis

The development of mathematical models for passenger comfort based on data obtained from observation in commercial airliners is outlined and discussed (see entry 5).

A simple example is presented to illustrate the application of the model to establish design criteria for a stability augmentation system to improve the ride quality of an aircraft.

7. JACOBSON, I. D. and KUHLETHAU, A. R.
Mathematical Modeling to Determine Criteria for Evaluating Human Acceptance of Transportation Systems
Short-Haul Air Transportation Program Memorandum Report 403206
August 1972 (Also: International Symposium on Systems Engineering and Analysis, Purdue University, October 23-27, 1972, Proceedings, Vol. II--Contributed Papers.)

Synopsis

Factor analysis performed on the results obtained from attitudinal surveys of travelers indicates that an appropriate way to represent traveler satisfaction would be a four-dimensional composite of commonly

encountered variables. The dimensions are:

- (1) a safety dimension--including reliability and dependability;
- (2) a cost-benefit dimension--involving convenience, value of time, etc.;
- (3) a "luxury" dimension--a mix of comfort, convenience, services and accommodations offered, aesthetics, and other similar descriptors.
- (4) an in-flight dimension--this characterizes the passenger's preference for how the time in flight will be spent and is strongly influenced by comfort.

An approach is developed for using this dimensional formulation in modal split analysis. A discussion of this concept indicates the potential versatility and scope of the approach over what has been possible with current state-of-the-art in modal split determinations.

Recent work at the University of Virginia in modeling the comfort dimension is presented and an application of this particular model is illustrated by deducing contours of equal comfort in multi-dimensional space. In particular the trade-off between vertical and transverse acceleration levels (the dominant motions in commercial aircraft) is presented. Such contours should be of great value to both the system operator (in specifying performance standards for vehicles) and to the vehicle designer (in providing guidance as to how to best satisfy these requirements).

8. KUHLETHAU, A. R. and JACOBSON, I. D.
Analysis of Passenger Acceptance of Commercial Flights Having Characteristics Similar to STOL
Short-Haul Air Transportation Program Technical Report 403208,
NASA Contractor Report CR-132282 (N73-27950)
March 1973 (Also: Canadian Aeronautics and Space Journal, vol. 19, no. 8, October 1973, pp. 405-409.)

Synopsis

Preliminary results are presented from a series of flight experiments utilizing three commuter-type aircraft (De Havilland Twin Otter, NORD 262, and Volpar Beech 18) in regular commercial service. Motion (six degrees of freedom), noise level, and temperature were measured at regular intervals during the flight. At the same time, one or two special test subjects on-board were asked to record their rating of comfort. Questionnaires were distributed to all passengers on-board, and they were asked to provide information on demographics, trip purpose, and flight experience, and also to evaluate the overall flight as to comfort and their willingness to fly again in this type of vehicle.

The results of the flight questionnaires are compared with those obtained previously from a ground-based sample (see entry 3) as appropriate. Ratings of passenger comfort are also analyzed by demographics and trip purpose; comparisons are given of the ratings made by passengers, crew, and test subjects; the ratings of the three types of aircraft used are given.

Since this is the initial analysis of comfort ratings obtained from regular passengers in flight, the results are of considerable interest. For example, for these aircraft types, seat comfort and seat spacing seems to be of great importance. Also there are clear indications that it may be possible to obtain quantitative response inputs from a small test subject group which will be representative of the general traveling public. Finally, by correlating comfort ratings with expressions of general satisfaction, it appears possible to estimate the percentage of passengers who will, on the average, be satisfied with a specific set of aircraft motions.

9. RUDRAPATNA, A. N. and JACOBSON, I. D.
Models of Subjective Response to In-flight Motion Data
Short-Haul Air Transportation Program Technical Report 403209,
NASA Contractor Report CR-140675 (N75-10708)
July 1973

Synopsis

A detailed analysis of the data obtained from a flight test program involving YS-11, F-227, and B-737 aircraft is presented (see entry 5). Six degree of freedom motion of the aircraft was recorded. Approximately 100 flight segments were used involving a variety of turbulence conditions over dissimilar terrain. One or two specially-selected test subjects flew aboard each flight and rated the comfort of the ride on a 5-point scale.

Regression analysis is used to develop subjective comfort models with the accelerations in the motion components as the independent variables. Two models are considered. In the first, subjective comfort is assumed to depend on RMS values of the accelerations. Variations in the model for different test subjects and different aircraft are also explored. The second model assumes a Rustenberg-type human response function in obtaining frequency weighted RMS accelerations, which are then used in a linear model. The form of the human response function is examined and the results yield a human response weighting function for different degrees of freedom.

10. RICHARDS, Larry G.
A Primer on Rating Scales, I--General Principles
Short-Haul Air Transportation Program Memorandum Report 403210
1973

Synopsis

One of the most important aspects involved in the development of a quantitative model based on subjective judgments is the manner in which these judgments are related to numerical values. The first step in this process is the design and utilization of a rating scale. In order to assist the investigator not thoroughly familiar with the instruments and procedures of psychological assessment, this report summarizes the general logic, assumptions, and methodology of rating scales.

11. JACOBSON, Ira D. and RUDRAPATNA, Ashok N.
The Applicability of Special Subject Groups for Assessing Passenger
Reaction to Flight Environments
Short-Haul Air Transportation Program Memorandum Report 403211,
NASA Contractor Report CR-132433 (N74-22774)
November 1973

Synopsis

Data obtained from flight tests using three different types of commuter aircraft (see entry 8) are analyzed to determine the relationships between comfort evaluations made by regular passengers, special test subjects, and the flight crew. Effects of flight length and the time history of the flight on subjective judgments of comfort are also studied.

The general conclusions reached are:

- (1) The flight crew does not appear to be able to predict passenger responses.
- (2) There is a direct relationship (neither linear nor a one-to-one correspondence) between the overall responses of passengers and test subjects.
- (3) A strong indication exists that an individual gives more importance to the latter portion of a flight than to the earlier portions in reaching an overall evaluation of comfort.

The consequences of conclusion (2) are particularly significant since it establishes a basis during the modeling process for extending the range of the variables which describe a flight environment over those randomly encountered in regularly-scheduled flights. Special flight or laboratory simulations can be designed using small groups of test subjects, and the results made representative of the general traveling public by means of the relationships devised in part (2).

12. GRUESBECK, Marta G. and SULLIVAN, Daniel F.
Aircraft Motion and Passenger Comfort Data from Scheduled Commercial
Airline Flights
Short-Haul Air Transportation Program Memorandum Report 403212,
NASA Contractor Report CR-2612 (N76-18043), March 1976
May 1974

Synopsis

This is a compilation of the ride quality data obtained in flight tests using six different types of aircraft during the period from 17 January 1972 to 29 March 1973 (see entries 5 and 8).

The following types of data are included:

- (1) root mean square (RMS) values of linear acceleration, angular acceleration or angular velocities, together with passenger subjective evaluations;
- (2) power spectra for the motions in each of six degrees of freedom;
- (3) scattergrams showing the probability density of the RMS accelerations in the vertical and transverse directions;
- (4) probability of occurrence distributions for the motion variables;
- (5) on-board noise levels during takeoff, climb, cruise, and descent.

13. SCHOULTZ, Michael B.
Simulators' Validation Study: Problem Solution Logic
Short-Haul Air Transportation Program Memorandum Report 403213
May 1974

Synopsis

There are many disadvantages in relying completely upon actual environments generated by aircraft in flight to obtain data for the determination of ride quality criteria or other types of studies in the field. Not only are flight experiments very expensive, but also they are only marginally controllable since, in general, the details of the flight environment cannot be predicted in advance. In fact, the experimenter is never assured that all the desired ranges of the variables can ever be obtained within a test program of restricted length.

It has been suggested that these difficulties could be overcome through the use of specially-designed laboratory instruments to simulate

the flight environment. While it may be possible to generate the desired ranges of the environmental variables with such devices, a new set of issues arise concerning their use. These relate to the validity of the laboratory techniques for eliciting subjective responses from test subjects which are truly representative of the flight environment which is being simulated.

This report outlines the logic and methodology associated with a determination of the validity of ground-based simulators as substitutes for actual aircraft environments in ride quality research.

14. RICHARDS, Larry G. and JACOBSON, Ira D.
Ride Quality Evaluation--I. Questionnaire Studies of Airline Passenger Comfort
Ergonomics, vol. 18, no. 2, 1975, pp. 129-150. (Also: NASA Contractor Report CR-139368 (N74-29460).)

Synopsis

This is the first of a series of papers designed to present in detail an analysis of the results obtained from the University of Virginia Short-Haul Air Transportation Program (for other reports in this series, see entries 16, 21, and 31). The objectives of this program are to assess passenger reactions to vehicle ride quality and to develop quantitative relationships relating these reactions to the variables which control the quality of the ride.

In this paper the results obtained from two questionnaires are discussed. One was administered to ground-based respondents and the other to passengers in flight. Respondents indicated the importance of various factors influencing their satisfaction with a trip, the perceived importance of various physical factors in determining their level of comfort, and the ease with which certain activities could be performed during flight. The in-flight sample also provided a rating of their level of comfort and of their willingness to fly again. Comfort ratings were examined in relation to:

- (1) type of respondent;
- (2) type of aircraft;
- (3) characteristics of the passengers;
- (4) types of on-board activities performed and ease of performance;
- (5) willingness to fly again.

15. MC CLURKEN, Eugene W., Jr., JACOBSON, I. D., and KUHLETHAU, A. R.
Preliminary Ride Quality Evaluation of the HM.2 Hoverferry
Short-Haul Transportation Program Memorandum Report 403216,
NASA Contractor Report CR-142290 (N75-17338)
December 1974

Synopsis

In late May 1974, the Hovermarine Corporation demonstrated their model HM.2 Hoverferry in the Hampton Roads area of Virginia. Observations on the ride quality of the craft were conducted by the University of Virginia using the techniques and methods previously developed for short-haul aircraft (see entry 5). Six-degree-of-freedom motion measurements were made, noise levels were recorded, and two experienced test subjects gave subjective responses to the quality of the ride which could be related in time to the measurement of the physical variables.

The overall quality of the ride is evaluated and passenger satisfaction is estimated. One of the most interesting aspects of the results was the observation of a strong dependence of ride acceptance on time. Acceptance remained constant for about 20 minutes and then decreased rather abruptly even though the physical variables were essentially constant.

It is also interesting to note that on the basis of previous experiments if the same motions had been encountered in a small aircraft, they would have elicited responses corresponding to a higher degree of comfort than those obtained from the Hoverferry.

16. JACOBSON, Ira D. and RICHARDS, Larry G.
Ride Quality Evaluation--II. Modelling of Airline Passenger Comfort
Ergonomics, vol. 19, no. 1, 1976, pp. 1-10.

Synopsis

This is the second of a series of papers designed to present in detail an analysis of the results obtained from the University of Virginia Short-Haul Air Transportation Program (for other reports in this series, see entries 14, 21, and 31). The objectives of this program are to assess passenger reactions to vehicle ride quality and to develop quantitative relationships relating these reactions to the variables which control the quality of the ride.

In this paper several techniques and candidate models for relating comfort to motion variables are evaluated. The data were obtained from actual commercial flights using 6 different vehicles ranging from a 15-passenger, twin turbo-prop aircraft used in commuter operations to a 115-passenger, twin-jet used in feeder line operations (see entries 5, 8, and 12).

The models evaluated include a simple linear regression relationship, a parametric least-squares power model, and a Stevens-type power law approach. The results show that the linear regression model, although not the "best" in a statistical sense, is sufficiently close to representing actual events so that further sophistication hardly seems warranted. Similarly, although models have been examined using all six-degrees of freedom of aircraft motion, for most applications a simplified version depending on only vertical and transverse RMS accelerations seems adequate.

17. BIGLER, William B., II and MC CLURKEN, Eugene W., Jr.
Total In-flight Simulator (TIFS), Preliminary Data
Short-Haul Air Transportation Program Memorandum Report 403218
December 1974

Synopsis

As a part of a joint research program using TIFS, sponsored and coordinated by the NASA/Langley Research Center, the University of Virginia was requested to obtain passenger-reaction data to a series of pre-programmed flight motions which could later be reproduced on ground-based motion simulators. TIFS is a specially-modified C131H aircraft owned by the U.S. Air Force Flight Dynamics Laboratory, and operated by the Calspan Corporation, which can be driven by a tape to produce a wide variety of motions while in flight.

The motions of interest were sinusoidal roll, sinusoidal vertical and lateral, random roll and yaw, random vertical and lateral combined, and random vertical. Sixteen 40-minute-duration driving tapes were prepared containing the time histories of the desired motions, the amplitudes having been selected on the basis of previously-obtained commercial flight data.

Ten test subjects were used and 7 test flights were made during the week of August 12-15, 1974. The engineering design and protocol for the experiments are presented in detail, as are the actual data obtained.

(For additional analysis of these experiments, see entry 20.)

18. NOSKOWITZ, David and JACOBSON, Ira D.
Passenger Demographics and Subjective Response to Commuter Aircraft in the Northeast
Short-Haul Air Transportation Program Memorandum Report 403219,
NASA Contractor Report CR-142876 (N75-23532)
December 1974

Synopsis

A preliminary analysis was made of data obtained from questionnaires completed by passengers using three commuter-type aircraft (see entry 8)

and an S-61 helicopter in regularly-scheduled service. The aircraft were operated by four different airlines. A total of 828 questionnaires were included in the study.

The degrees of comfort and satisfaction expressed by the passengers are correlated with a variety of variables and procedures which could affect these judgments. Included are

- (1) demographics of the sample population;
- (2) trip motivation;
- (3) traveling experience;
- (4) aircraft design characteristics;
- (5) aircraft operating procedures.

One of the most valuable conclusions reached was the identification of the seat design and spacing as perhaps one of the most important parameters affecting passenger comfort and satisfaction.

19. DEPTULA, David A.
Ride Quality Research Data Acquisition Phase--Canadian STOL Project
(Airtransit)
Short-Haul Air Transportation Program Interim Report
May 1975

Synopsis

Procedures are defined for obtaining measurements of aircraft environment and subjective reaction of passengers and test subjects to ride comfort and overall satisfaction during regular operations of the Canadian STOL Demonstration Project. This project provides city-center STOL service between Montreal and Ottawa using De Havilland DHC-6 (Twin Otter) aircraft specially modified to provide the potential for increased comfort. The aircraft are operated according to professional airline standards under the name and logo of Airtransit.

A very preliminary presentation of the data obtained from 61 flights (413 passenger responses) made during two separate time periods is given.

20. MC CLURKEN, Eugene W., Jr.
University of Virginia Acquisition of Passenger Ride Quality Data Aboard
the Total In-flight Simulator (TIFS)
Short-Haul Air Transportation Program Technical Report 403220,
NASA Contractor Report CR-145957 (N76-14787)
October 1975

Synopsis

There is no completely satisfactory source of data for use in developing quantitative models for predicting passenger acceptance of air transportation vehicles. Regular commercial flights are often used, but these have several drawbacks, including the inability to obtain reactions to certain types and ranges of motion which are infrequently or seldom encountered. Several types of laboratory simulators are available which can produce a wider range of carefully-controlled motions and are relatively inexpensive to operate. However, the fidelity of the reproduction of the flight environment and the equivalence of test subject responses to similar stimuli administered on the ground and in the air have never been established.

This report documents the first component of an effort undertaken by the University of Virginia to establish the validity of ground-based simulation on the Passenger Ride Quality Apparatus (PRQA) at the NASA/Langley Research Center (see also entries 17 and 34). The plan is to compare the subjective reactions of the same group of test subjects to identical sets of motions encountered in flight and on PRQA. The flight motions were provided through the use of the Calspan Corporation's Total In-flight Simulator aircraft (TIFS).

The experimental procedure is discussed in detail, the data obtained are documented in a standardized format, and the principal results obtained and conclusions drawn are discussed.

21. RICHARDS, Larry G. and JACOBSON, Ira D.
Ride Quality Assessment--III. Questionnaire Results of a Second Flight Program
Short-Haul Air Transportation Program Memorandum Report 403221
October 1975 (Also: accepted for publication by Ergonomics, 1977.)

Synopsis

This is the third of a series of papers designed to present in detail an analysis of the results obtained from the University of Virginia Short-Haul Air Transportation Program (for other reports in this series, see entries 14, 16, and 31). The objectives of this program are to assess passenger reactions to vehicle ride quality, and to develop quantitative relationships relating these reactions to the variables which control the quality of the ride.

A questionnaire was completed by 861 passengers on regularly-scheduled flights of four commuter airlines using four different types of aircraft (see entry 18). This paper presents a detailed analysis of the data obtained. Questions assessed the major demographic variables, attitudes toward flying, frequency of flying, experience of airsickness, and perception of detailed aspects of the physical environment. Passengers also rated their overall comfort level and their willingness to fly again.

The results show that passengers perceive motion, noise, and seat factors as the primary determinants of their comfort. Rated comfort is strongly related to willingness to fly again. Incidence of airsickness was low. Reactions to various aspects of the environment were different for males and females.

22. STONE, Ralph W., Jr., PAUL, Arthur S., and KUHLETHAU, A. R.
The Reaction of Passengers to the Terminal Area
Short-Haul Air Transportation Program Memorandum Report 403222
(in preparation)

Synopsis

With the recent overcrowding of airport terminals and their access systems, this aspect of a journey by air becomes increasingly important in influencing the acceptance of the overall trip. This is particularly true in the short-haul market where competing modes usually exist. Satisfaction with the terminal area may be a decision variable per se, and/or it might have a strong preconditioning effect on the passenger's perception of vehicle ride quality.

Methodologies and experimental procedures are developed for determining the reaction of the passenger to the various functions performed in the terminal, and for determining how these might combine to provide an overall evaluation of a given terminal. Since the terminal represents a distinct set of experiences for passengers using the terminal as a point of origin, a point of destination, and a transfer point, each of these cases must be considered independently.

23. DEPTULA, David A.
NASA/FRC Wake Turbulence Flight Test Program--Ride Quality Aspects
Short-Haul Air Transportation Program Memorandum Report 403225,
NASA Contractors Report CR-145700 (N76-11040)
November 1975

Synopsis

Ride quality observations were made on a Boeing 747 aircraft being operated in a terminal approach mode with spoilers raised at several settings up to 45°. Previous tests had shown that the use of raised spoilers in the landing configuration reduces vortex generation significantly, but with an apparent increase in buffeting of the aircraft. The purpose of the flight tests reported herein was to obtain the necessary data to use the University of Virginia ride quality model to assess probable passenger acceptance of this landing approach technique.

An instrumentation package to measure six-degree-of-freedom motion was located approximately 31 feet aft of the aircraft's center of gravity. Recordings obtained during each flight segment provided the RMS values of

the accelerations and rates with their standard deviations. These values were introduced into the University of Virginia comfort rating model (see entry 16) and the comfort response calculated. These ratings were then transformed into values of passenger satisfaction.

A complete presentation of reduced data is made, and the predicted implications of spoiler setting on passenger satisfaction are discussed for a variety of maneuver conditions in the approach pattern.

24. JACOBSON, Ira D., KUHLETHAU, A. R., and RICHARDS, Larry G.
Application of Ride Quality Technology to Predict Ride Satisfaction for
Commuter-type Aircraft
Proceedings, 1975 Ride Quality Symposium and Workshop, Williamsburg,
Virginia, August 11-15, 1975, NASA TM X-3295 (DOT-TSC-OST-75-40),
(N76-16757), pp. 45-64
November 1975

Synopsis

A method is described for assessing the probable passenger satisfaction with the ride quality on all types of transportation vehicles. The method is applicable to both existing systems as well as future ones, and can be used for evaluation, design, and decision making. Basically, it relates the environment in which the vehicle must be used and the performance characteristics of the vehicle to determine the probability of satisfying the passenger.

The method is illustrated by application to a series of typical commuter-type aircraft. Extensive results are presented for the De Havilland DHC-6 (Twin Otter) and comparisons are made with the Breguet 941, Cessna 182, and Douglas DC-8.

The environmental forcing function is introduced as a standard turbulence spectrum at a given altitude over a certain type of terrain. Several such spectra are used to simulate a variety of operation conditions. This forcing function is then imposed on the aerodynamic response characteristics of the vehicle under study. This provides a computation of the motion components (accelerations and rates) at any point in the vehicle. Finally these motion components can be inserted into the University of Virginia Ride Quality Model (see entry 16) and the probable distribution of passenger satisfaction estimated.

25. RICHARDS, Larry G., KUHLETHAU, A. R., and JACOBSON, Ira D.
Passenger Ride Quality Determined from Commercial Airline Flights
Proceedings, 1975 Ride Quality Symposium and Workshop, Williamsburg,
Virginia, August 11-15, 1975, NASA TM X-3295 (DOT-TSC-OST-75-40),
(N76-16772), pp. 409-436
November 1975

Synopsis

A complete and thorough review of the objectives, techniques, and conclusions of the University of Virginia ride quality research program to date is presented. The following problem areas are considered:

- (1) analysis of the vehicle environment;
- (2) methods for analyzing passenger reactions;
- (3) experimental programs conducted;
- (4) data obtained from questionnaires;
- (5) comfort response as a function of vehicle;
- (6) physical factors related to comfort;
- (7) seat variables;
- (8) perceived relations between environmental factors;
- (9) model development.

26. STONE, Ralph W., Jr.
Simulator Studies and Psychophysical Ride Comfort Models
Proceedings, 1975 Ride Quality Symposium and Workshop, Williamsburg,
Virginia, August 11-15, 1975, NASA TM X-3295 (DOT-TSC-OST-75-40),
(N76-16780), pp. 615-644
November 1975

Synopsis

A series of experiments is described which was designed to evaluate the effect of specific selected motion stimuli on the comfort response of humans. The experiments were performed on the NASA/Langley Visual Motion Simulator and the motion stimuli were restricted to a single degree of freedom and to two degrees of freedom. The various conditions for any motion component included variations in the magnitude of the RMS motion stimulus and variations in the power spectral shape of the motion stimulus. The spectra were varied between 0 and 2 Hz to represent variations of power spectra measured in flight.

The experimental procedures are described and the results presented and analyzed.

Models with responses proportional to the logarithm of the stimuli are proposed for single degree of freedom motion responses. The subjects appeared much more sensitive to random transverse accelerations and rolling velocities than to the other degrees of freedom. For combinations of linear accelerations, a model based on the resultant

acceleration is proposed. For other motion combinations, models based on the concept of a primary response to the dominant stimulus with small modifications from the other stimuli are proposed. Relatively good correlation exists between the models and the mean subjective ride comfort response ratings. The data and models suggest a synergistic effect of certain motion combinations, for example, the presence of yawing motions seems to cause greater tolerance to rolling motions.

27. JACOBSON, Ira D.
Construction and Verification of a Model of Passenger Response to STOL Aircraft Characteristics
SAE National Air Transportation Meeting, New York, New York, May 18-20, 1976, Paper #760525.
February 1976

Synopsis

Experimental data on passenger satisfaction obtained from two separate commercial commuter airline operations are compared with the ability of analytical approaches to predict these evaluations. The two flight programs involved the same basic aircraft (a De Havilland DHC-6 Twin Otter) but operated under quite different conditions. In one, a U.S. commuter airline, the aircraft was used in its normal configuration with three-abreast seating (18-passenger capacity). In the other, Airtransit between Montreal and Ottawa, deluxe two-abreast seating was used (11-passenger capacity), additional air conditioning provided, and various ground-related amenities added to the service. Stage lengths and flight times were generally similar.

One analytical method used involved the estimation of the aircraft motion based upon using selected air turbulence spectra and aircraft transfer characteristics (see entry 24). The other method used actual flight measurements of the motion. In both cases the resulting motions were inserted into the University of Virginia ride quality model (see entry 16) and the expected passenger acceptance computed. These expectations are then compared with the actual passenger ratings obtained by questionnaires completed during the flight.

The procedures, both experimental and analytical, are discussed and the results presented. In the case of the regular DHC-6, the agreement between the computations based on motion measurement and the actual passenger response was very good. It was somewhat better than the predictions based upon the complete analytical approach, perhaps indicating deficiencies in the knowledge of turbulence spectra and the aircraft transfer function. For the special Airtransit Twin Otter, the actual passenger acceptance was much better than that predicted by either approach. This is felt to be a bias introduced by the deluxe conditions under which the aircraft is operated. These are not reflected in any of the data used to generate the University of Virginia ride quality model.

28. RANSONE, Robin K.
Chelsea STOLport--The Airline View
SAE Air Transportation Meeting, New York, New York, May 18-20, 1976,
Paper #760523
May 1976

Synopsis

In 1970 American Airlines gave serious consideration to the inauguration of a city-center STOL air service between the major cities in the Northeast. The key to the operation was to be a floating STOLport located in the Hudson River adjacent to the Chelsea residential community of New York City. The project was eventually abandoned because of the effective and well-organized opposition of the citizens of the Chelsea neighborhood.

The nature of the confrontations, the interactions of the principals, and the lessons learned as viewed by the airlines are analyzed and summarized. This material should be of value to any project where the implementation of technological advances is perceived by the public as a threat to their quality of life.

29. RICHARDS, Larry G., JACOBSON, Ira D., and KUHLETHAU, A. R.
Determinants of Rated Comfort for Airline Passengers
84th Annual Convention of the American Psychological Association, The
Society of Engineering Psychologists, Washington, D.C., September
3-5, 1976
September 1976

Synopsis

A general summary of the University of Virginia ride quality program designed to make the principal results known to this scientific community in advance of other publications which are always subject to unpredictable delays.

30. CONNER, D. William and JACOBSON, Ira D.
Passenger Ride Comfort Technology for Transport Aircraft Situations
NASA TM X-73953 (Also: "Aircraft Safety and Operating Problems,"
October 1976 NASA SP-416, 1976, pp. 563-584.)

Synopsis

A brief overview of NASA research in ride comfort and its applications is presented. A discussion of the origin of ride comfort problems focuses on three areas:

- the environment in which the aircraft operates;
- the operational aspects and maneuvers of the aircraft;

- the aircraft configuration.

The nature of the research program is discussed briefly and the results as contained in the following three useful types of ride comfort relations are discussed:

- (1) Comfort Model Reaction--to provide the subjective transfer function for relating ride environment to ride comfort.
- (2) Ride Satisfaction Relation--to provide the subjective value function for relating ride comfort to trip satisfaction.
- (3) Response Integration Relation--to provide a method for appropriately weighting and summing the series of local comfort ratings (experiences) of a trip to obtain an overall evaluation of satisfaction.

The following applications of these results to air transportation problems are described:

- evaluation of the effect of an uprigged spoiler on the trade-off between reduced trailing vortices and ride comfort;
- identification of the effect of proposed localizer/glide slope capture maneuver on passenger comfort;
- definition of equi-comfort levels in aircraft environments;
- importance of wing loading on ride quality;
- prediction of total trip ride characteristics.

31. JACOBSON, Ira D. and RICHARDS, Larry G.
Ride Quality Evaluation--IV. Models of Subjective Reaction to Aircraft Motion
Short-Haul Air Transportation Program Memorandum Report 403227
December 1976 (Also: accepted for publication by Ergonomics, 1977.)

Synopsis

This is the fourth of a series of papers designed to present in detail an analysis of the results obtained from the University of Virginia Short-Haul Air Transportation Program (for other reports in this series, see entries 14, 16, and 21). The objectives of this program are to assess passenger reactions to vehicle ride quality, and to develop quantitative relationships relating these reactions to the variables which control the quality of the ride.

Previous papers in this series have analyzed the data obtained from questionnaire surveys, and examined various modeling approaches using

these data as well as test subject reactions and measurements of the vehicle environment. In this final paper, the work is summarized and the best models based on all available data from four aircraft (Beech, Nord, Twin Otter, and S-61 helicopter) are presented and discussed.

32. KUHLTHAU, A. R. (editor)
Proceedings and Findings of the 1976 Workshop on Ride Quality, 1976
Workshop on Ride Quality, Lake Morey Inn, Fairlee, Vermont, October
13-15, 1976
NASA CP-2006, DOT-TST-77-38
December 20, 1976 (Also: Short-Haul Air Transportation Program Summary
Report 403228)

Synopsis

This report presents the proceedings and findings of the 1976 Workshop on Ride Quality which was organized and conducted by the Task Force on Ride Quality of the Transportation Research Board (A3B51). The workshop was supported by the U.S. Department of Transportation with the assistance of the NASA/Langley Research Center.

Following the 1975 Symposium and Workshop on Ride Quality held in Williamsburg, Virginia, it was agreed that it would be of value to hold a second workshop to relate the current knowledge to the needs in several key areas of the ride quality system, and thus identify the major technology gaps which now exist. This then was the objective of the 1976 Workshop.

Four working groups were organized:

- A. Surface Vehicles--J. Karl Hedrick, MIT, Chairman

Concerned with the formulation of vehicle characteristics including the description of the appropriate inputs to the vehicle and the vehicle transfer function for all land-based vehicles.

- B. Air/Marine Vehicles--D. William Conner, NASA/Langley, Chairman

Responsibility is similar to group A, except that the concern is with aircraft and high-speed marine vehicles.

- C. Passenger Transfer Function--Ira D. Jacobson, Univ. of Virginia, Chairman

Concerned with the subjective response of passengers in terms of comfort evaluation including all normal stimuli associated with the vehicle. All modes were considered.

D. Value Function--E. Donald Sussman, DOT/Transportation Systems Center, Chairman

Also concerned with subjective evaluation, in this case of overall passenger satisfaction under circumstances where comfort is considered along with other vehicle and system parameters. All modes were considered.

The reports and conclusions of these four working groups are presented in this summary. In general, the report follows the format given below:

- (1) define the scope of the area;
- (2) identify the major technology gaps in the area;
- (3) Identify specific problems for each major gap;
- (4) whenever possible, rate the priority of each problem;
- (5) comment upon the contributions which might be made through activities of a committee of the Transportation Research Board.

33. SCHAEDEL, Stephen F.
Human Factors In the Design of Passenger Seats for Commercial Aircraft--
A Review
Short-Haul Air Transportation Program Technical Report 403229,
NASA Contractor Report CR-152627 (N77-20775)
March 1977

Synopsis

The principal results available from research conducted since the early part of this century are summarized and reviewed. Interpretations are made to relate this work to current problems in aircraft seating, since this has been shown to be an extremely important consideration in the passenger's perception of ride comfort and satisfaction.

The material is presented from three perspectives:

- (1) bio-static considerations for a seated person;
- (2) bio-dynamic considerations for a seated person on commercial aircraft;
- (3) passenger seat design and technology for commercial aircraft.

34. BIGLER, William B. II
Validation of the Passenger Ride Quality Apparatus (PRQA) for Simulation
of Aircraft Motions for Ride Quality Research
Short-Haul Air Transportation Program Technical Report 403230
March 1977

Synopsis

This report documents the second component of an effort undertaken by the University of Virginia to establish the validity of ground-based simulation of an aircraft environment using the PRQA located at NASA/Langley Research Center. The plan compares the subjective reactions of the same group of test subjects to identical sets of motions and other environmental stimuli both in flight and on PRQA. The flight tests were described in entries 17 and 20 and used the Calspan Total In-flight Simulator (TIFS).

A series of four tests were performed on PRQA with the following sets of stimuli:

- motions only;
- motions and noise;
- motions, noise, and visual;
- motions and visual.

All motions were generated from the same tapes used in the TIFS flights.

The test procedures are described and the results of a detailed statistical analysis of the data are presented and discussed.

It was concluded that in general PRQA seems to offer a valid simulation of aircraft motion. Some suggestions are made for improving the non-motion environmental stimuli.

35. KUHLETHAU, A. R. and WICHANSKY, Anna M. (editors)
Summary Report: Workshop on Vehicle Ride Quality, Held at Williamsburg,
Virginia, August 13-15, 1975
NASA CP-2013
April 1977 (Also: Short-Haul Air Transportation Summary Report 403231)

Synopsis

In August of 1975 a joint Symposium and Workshop on Vehicle Ride quality was held. The goal of the symposium was to provide an open forum for the presentation and discussion of latest contributions to the state-of-the-art, thus improving the technology base of ride quality information applicable to current and proposed transportation systems (for U.Va. contributions, see entries 24, 25, and 26).

The three-day workshop immediately following the symposium was conducted to review the information gained from the symposium, combine it with previous knowledge, and summarize the state-of-the-art as seen by the invited participants (59 in number).

Four major discussion groups were formed:

1. Accomplishments in Ride Quality Research--Present and Near Future

Chairman: Ira D. Jacobson, University of Virginia
Co-Chairman: John P. Jankovich, U.S. DOT/Transportation Systems Center

2. Needs of the Transportation Community--Present and Near Future

Chairman: D. William Conner, NASA/Langley Research Center
Co-Chairman: Richard Scharr, U.S. DOT/Federal Railroad Administration

3. Ride Quality Research Techniques

Chairman: E. Donald Sussman, U.S. DOT/Transportation Systems Center
Co-Chairman: Thomas K. Dempsey, NASA/Langley Research Center

4. Ride and Environment Control Techniques

Chairman: J. Karl Hedrick, MIT
Co-Chairman: Anthony J. Healey, University of Texas at Austin

The reports of these four working groups are presented in some detail (159 pages).

36. CLARKE, M. J.

A Summary of Evidence Available on Time-Duration Effects on Comfort and Task Proficiency Under Vibration
Short-Haul Air Transportation Program Report UVA/528060/ESS77/109
April 1977

Synopsis

The evidence which the author has unearthed on time dependence effects relating to "reduced comfort" and to "fatigue/reduced proficiency" in the presence of vibration levels appropriate to a range of transport situations is analyzed and discussed. The work is that of many experimenters and involves both field tests and studies using laboratory simulators of motion. The levels of vibration, and the frequency ranges involved cover a wide range from very comfortable vehicles to extremely harsh-riding vehicles travelling across rough terrain.

The conclusion is reached that there is no evidence to support the assertion of a time dependence effect such as is quoted in ISO 2631.

37. JACOBSON, I. D. and MC PHERSON, R. F.
SEGMENT User's Manual--A Computer Program to Predict Comfort and Satisfaction of Aircraft Passengers
Short-Haul Air Transportation Program Technical Report UVA/528060/ESS77/
110
July 1977

Synopsis

This user's manual documents a computer program designed to predict the comfort and satisfaction of aircraft passengers. The program can be used in either an interactive or batch mode, and has two major options. First, given aircraft properties and flight profiles, the program will generate cumulative probability distribution functions of both passenger comfort and satisfaction. Second, for flights in which the environmental variables existing in the aircraft are known, the mean passenger comfort and satisfaction level is computed.

The general background of model development and the details of the mathematical formulations are presented, as are the complete computer programs and the instructions for their use.

ABSTRACT

Criteria and methodology have been developed in the area of ride quality for assessing the potential acceptability to the traveling public of transportation systems. This final report of a six-year major effort summarizes the strategies, activities, results and conclusions, and properly orients the reader to the appropriate prior reports. A complete listing of the thirty seven publications is appended and a brief summary of each is included.

1. Report No. NASA CR-145250		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle THE DEVELOPMENT OF A MODEL FOR PREDICTING PASSENGER ACCEPTANCE OF SHORT-HAUL AIR TRANSPORTATION SYSTEMS				5. Report Date September 1977	
				6. Performing Organization Code	
7. Author(s) A. Robert Kuhlthau and Ira D. Jacobson				8. Performing Organization Report No. UVA/528060/ESS77/111	
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				11. Contract or Grant No. NGR 47-005-181	
12. Sponsoring Agency Name and Address National Aeronautics & Space Administration Washington, DC 20546				13. Type of Report and Period Covered Contractor Report	
				14. Sponsoring Agency Code	
15. Supplementary Notes					
<p>16. Abstract This report concludes an extensive grant effort which achieved the intended objective of developing meaningful criteria and methodology for assessing, particularly in the area of ride quality, the potential acceptability to the traveling public of present and future transportation systems. Major experimental and analytical effort was expended over six years in developing the problem solution plan and test methodologies, in determining the importance of system features to the air traveler, in modeling the travelers' acceptance as a function of ride, in validating models and in applying the models to various situations. Thirty-seven prior publications report these efforts. This final report summarizes the strategies, activities, results, and conclusions, and properly orients the reader to the appropriate publications for details. A complete listing of all publications issued is appended and a brief summary of each is included.</p> <p>Ride quality was found to be one of the important variables affecting the decision of users of air transportation, and to be influenced by several environmental factors, especially motion, noise, pressure, temperature, and seating. Models were developed to quantify the relationship of subjective comfort to all of these parameters and then were exercised for a variety of situations. Passenger satisfaction was found to be strongly related to ride quality and was so modeled. A computer program was developed to assess the comfort and satisfaction levels of passengers on aircraft subjected to arbitrary flight profiles over arbitrary terrain. A model was deduced of the manner in which passengers integrate isolated segments of a flight to obtain an overall trip comfort rating. A method was established for assessing the influence of other links (e.g., access, terminal conditions) in the overall passenger trip.</p>					
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